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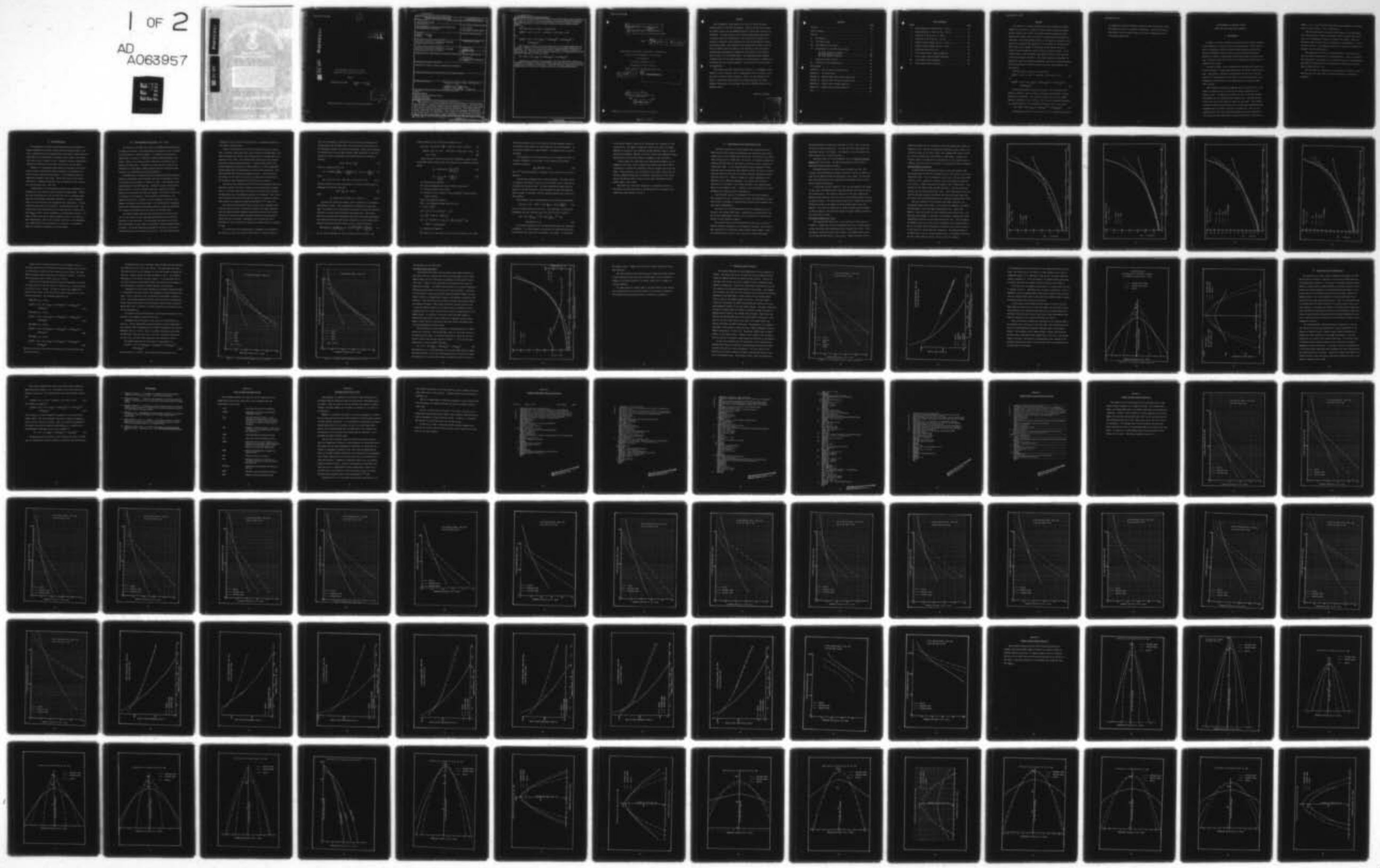

AFIT/GNE/PH/78D-23

AN IMPROVEMENT TO THE WSEG FALLOUT MODEL LOW YIELD PREDICTION CAPABILITY

THESIS

AFIT/GNE/PH/78D-23 Norman H. Ruotanen
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The analysis of residual radiation from the detonation of nuclear weapons has resulted in a number of nuclear fallout prediction models. The most widely used of these is the WSEG (Weapons System Evaluation Group) fallout model which is a series of empirically based analytical algorithms. This study modifies three of the empirical parameters which control the transport and deposition of the fallout for the WSEG model. These three are the height of the center of the nuclear cloud, the cloud's vertical thickness, and the cloud's horizontal radius. In the original model, these parameters were empirical fits to data

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from four of the early nuclear test shots. This study updates the parameters by using more recent and thorough experimental data and by using information from the Department of Defense Fallout Prediction System (DELFIC Computer Model).

The cloud center's height is updated from:

$$H_c(KFT) = 44.0 + 6.1 \ln Y - .205 (\ln Y + 2.42) \left|\ln Y + 2.42\right|$$

to:

$$H_c(KFT) = 50.7 + 20.4 \log_{10}Y + 3.50(\log_{10}Y)^2 + 2.40(\log_{10}Y)^3 + 0.60(\log_{10}Y)^4$$

The Gaussian spatial activity distribution of the original WSEG model is retained. However, both the vertical and horizontal standard deviations are modified. The vertical standard deviation is changed from $\sigma_H = 0.180\ H_c$ to $\sigma_H = 0.125\ H_c$. The horizontal standard deviation, σ_o, is multiplied by a yield dependent adjustment factor, AK, where

$$AK = 0.90 - 0.40 \log_{10}Y + 0.30(\log_{10}Y)^2 + 0.10(\log_{10}Y)^3$$

Inserting the modified cloud parameters into the WSEG model results in significantly improved fallout predictions below 500 kilotons yield when DELFIC is used as a standard of comparison. Above 500 kilotons, predictions from the updated model do not differ significantly from the original WSEG model.

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Preface

This independent study began as an effort to codify the basic nuclear effects on the TI-59 calculator. Fallout was the first subject of in-depth study with the WSEG/NAS modified fallout model selected for codifying. Critical analysis of the model revealed major deficiencies in fallout prediction capabilities. The deficiencies appeared to be related to inaccurate cloud parameter data used in empirically fitting the original model. With improved cloud information available, such as from the DELFIC prediction model, it was decided to refit the model's calculational algorithms and compare the new results to the original model as well as to the DELFIC model. The comparative model analysis confirmed that the low yield capability of the WSEG model is significantly improved by the corrected geometry. All work with the TI-59 project was terminated.

This author gratefully appreciates Professor C. J. Bridgman, thesis advisor, for his catalytic role in prompting the in-depth study of fallout which resulted in these findings. Thanks are also extended to Dr. Kathy S. Gant and the Solar and Special Studies Section, Oak Ridge National Laboratory, for providing a copy of the FORTRAN version of the WSEG/NAS model.

Norman H. Ruotanen

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Abstract

The analysis of residual radiation from the detonation of nuclear weapons has resulted in a number of nuclear fallout prediction models. The most widely used of these is the WSEG (Weapons System Evaluation Group) fallout model which is a series of empirically based analytical algorithms. This study modifies three of the empirical parameters which control the transport and deposition of the fallout for the WSEG model. These three are the height of the center of the nuclear cloud, the cloud's vertical thickness, and the cloud's horizontal radius. In the original model, these parameters were empirical fits to data from four of the early nuclear test shots. This study updates the parameters by using more recent and thorough experimental data and by using information from the Department of Defense Fallout Prediction System (DELFIC Computer Model).

The cloud center's height is updated from:

$$H_c(\text{KFT}) = 44.0 + 6.1 \ln Y - .205 (\ln Y + 2.42) \left|\ln Y + 2.42\right| \quad (1)$$

to:

$$H_c(\text{KFT}) = 50.7 + 20.4 \log_{10} Y + 3.50(\log_{10} Y)^2 + 2.40(\log_{10} Y)^3 + 0.60(\log_{10} Y)^4 \quad (2)$$

The Gaussian spatial activity distribution of the original WSEG model is retained. However, both the vertical and horizontal standard deviations are modified. The vertical standard deviation is changed from $\sigma_H = 0.180\ H_c$ to $\sigma_H = 0.125\ H_c$. The horizontal standard deviation, σ_o, is multiplied by a yield dependent adjustment factor, AK, where

$$AK = 0.90 - 0.40 \log_{10} Y + 0.30(\log_{10} Y)^2 + 0.10(\log_{10} Y)^3 \quad (3)$$

Inserting the modified cloud parameters into the WSEG model results

in significantly improved fallout predictions below 500 kilotons yield when DELFIC is used as a standard of comparison. Above 500 kilotons, predictions from the updated model do not differ significantly from the original WSEG model.

AN IMPROVEMENT TO THE WSEG FALLOUT

MODEL LOW YIELD PREDICTION CAPABILITY

I. Introduction

An important aspect of military strategy and civil defense planning is the prediction of fallout from nuclear detonations. Current limitations on atmospheric nuclear testing preclude developing predictions based on experimental results under typical battlefield conditions. Therefore, a number of empirically based fallout models have been developed. The most widely used of these is the WSEG fallout model which is updated in this study.

As early as 1965, it was recognized that the WSEG model tends to be overly pessimistic in predicting casualties from residual nuclear radiation. Two factors, inaccurate cloud geometry and the use of the Way-Wigner $T^{-1.2}$ approximation for the decay of the fission products, were recognized as contributing to the overprediction of fallout by WSEG (Ref. 1:9,207).

More recently, Norment has suggested that the deficiencies of the model are primarily due to errors in the activity deposition rate function, g(t). In addition, he points out that the cloud's altitude and geometry are not consistent with updated data. The WSEG nuclear cloud is too low and too small in radius at low yields. This results in fallout contour patterns which are too narrow with excessively high concentrations of activity too close to ground zero. That is, the isodose contour lines are longer and narrower than those observed in test shots and those predicted by sophisticated fallout models such as

DELFIC. It is in the low-yield range that these weaknesses in the WSEG model are most apparent. (Ref. 2:84-90;3:29)

This study has applied corrected cloud geometry to the WSEG model. The corrected cloud is higher and thinner than the original WSEG cloud. Also, it is significantly larger in radius at low yields. Since the deposition rate function, g(t), is dependent on cloud geometry, it also has been improved. The improvements made to the model are validated by comparison to the DELFIC model.

The comparisons show that the improved model is much more consistent with DELFIC results than the original model is. This is a significant improvement since Norment, in a recent evaluation of fallout models, concluded that DELFIC has the best prediction capability for six test shots considered (Ref. 3:6).

For the reader not familiar with the parlance of fallout, a list of abbreviations and terms common to fallout literature is provided in Appendix A.

II. The DELFIC Model

The Department of Defense Fallout Prediction System (DELFIC) is widely recognized as the most credible fallout prediction model. However, a widespread lack of understanding of the model, combined with its requirements for large amounts of computer central memory and computation time, tends to inhibit its use. Appendix B provides supplementary information on DELFIC for the reader not familiar with the model.

Norment, in a comparative model analysis using data from six test shots, recently concluded that DELFIC conforms to experimental data better than any other prediction model. It was therefore used as a comparison standard in this study. Direct test data was not used in this effort. Norment's evaluation found that DELFIC is most accurate up to 50 kilotons yield. (Ref 3:6)

A simplified set of environmental conditions was established for obtaining all data extracted from the DELFIC and WSEG models. DELFIC was used with Nevada test site soil and with the U.S. Standard atmosphere for mid-latitude, spring/fall conditions. A ground roughness factor of 0.5 was used for all accumulated dose comparisons. A steady 15 mph wind was used at all altitudes. No wind shear was used. The contour width plots presented give the normalized unit reference dose rates ($\dot{D}_{H+1}$) without terrain shielding or instrumentation factors. All contour length plots use the ground roughness factor of 0.5 and give dose accumulated to either four or twenty four hours. All comparisons use a 100% fission device detonated at the surface. No percentage figure of accuracy is assigned to the three models.

III. The WSEG/NAS Fallout Model (Ref. 2;4;5)

The version of the WSEG model used is the WSEG-10/NAS modified fallout model as provided to Oak Ridge National Laboratory by Leo A. Schmidt of the Institute for Defense Analysis. To simplify and clarify the nomenclature, the model is referred to simply as WSEG throughout this report. WSEG, in its various versions and forms, has been in use by analysts for many years. Although its results can be in error due to deficiencies in the model, systems analysts persist in using the model because of its computational ease and simplicity.

The WSEG model is structured around an empirically based deposition function, called g(t), which represents the rate of deposition of fallout activity on the ground as a function of time. This function can be conceptualized in the following way. Consider a nuclear surface burst which results in a cloud of fallout particles, assumed to be microspheres, at an altitude well above the ground. The center of this cloud is located at an altitude H_c. This altitude is determined by the weapon's total yield. Consider a no wind condition so that the cloud remains stationary over the burst point. The following four paragraphs present the circumstances and processes which are assumed in describing the transport and deposition of the fallout by the WSEG model.

The fission product radiation and unburned fuel were fully vaporized at the instant of burst and began resolidification into fallout particles as the cloud rose. The resulting solid particles will have some distribution of sizes from a few microns to several hundred microns in radius. The actual distribution depends on the type of soil which was vaporized and on the weapon's total yield. The total radioactivity

contained in and on these fallout particles is determined primarily by the weapon's fission yield.

Some of the particles will fall while the cloud is still rising. This is known as stem fallout and is not treated by the WSEG model. The model transports and deposits local fallout which is roughly 80% of the activity in the cloud. The remaining 20%, consisting of the smallest particles, becomes world-wide fallout. For this local fallout, the source normalization factor, NF, used by WSEG is 2×10^6 roentgens/hr/fission megatron/st mi^2 normalized to one hour after detonation. This value includes both fission and induced activity. For bursts above the surface of the earth, the activity is adjusted by the fraction of the fireball's lower hemisphere which intersects the surface.

The various size particles will fall from the stationary cloud with different terminal velocities, raining on the ground below at varying times. It is clear that there is some function, g(t), which describes the deposition rate of radioactive material on the ground. This rate of material deposition does not include the effects of radioactive decay. Decay effects are applied by using the Way-Wigner $T^{-1.2}$ decay rule.

The concept of a deposition function, g(t) can be extended to the real situation with wind. When wind is applied, the larger particles reach the ground somewhat downwind from ground zero while the smaller particles are carried to greater distances downwind from ground zero before they hit the ground. Nonetheless, the function g(t) still describes the rate of arrival of activity at surface level as a function of time.

It is clear that this function g(t) is dependent on the height of the cloud, H_c, and on the vertical distribution of activity about H_c.

The size distribution of particles and the activity distribution with various sizes also influence g(t), as do the density and viscosity of the atmosphere between the cloud and the ground. Rather than attempting to calculate g(t) from all these factors, WSEG, using four of the early nuclear test shots, approximates g(t) empirically by the following equation.

$$g(t) = \frac{1}{T_c} \exp - \left(\frac{t}{T_c}\right) \qquad (4)$$

where T_c is empirically fit as:

$$T_c = 1.0573203 \left[\frac{12}{60} H_c - 2.5\frac{(H_c)^2}{(60)^2}\right] \left[1 - 0.5 \exp - \frac{(H_c)^2}{(25)^2}\right] \qquad (5)$$

where

$$H_c = 44.0 + 6.1 \ln Y - .205 (\ln Y + 2.42) \left|\ln Y + 2.42\right| \qquad (5.a.)$$

The g(t) function is easily transformed to a distance function g(l) by applying the effective wind, EFW.

$$g(l) = \frac{1}{L_o} \exp - (l/L_o) \qquad (6)$$

where

$$L_o = EFW.T_c \text{ and } \int_0^{\infty} g(l)\, dl = \int_0^{\infty} g(t)\, dt \qquad (6.a.)$$

The activity within the nuclear cloud is assumed to be a Gaussian distribution in space. This distribution is supported by early test data. The limits of the distribution are defined as being four standard deviations in extent both vertically and horizontally. The density function ρ describes the distribution where DWD is distance from ground zero along the effective wind vector, referred to as the hotline, CWD is distance crosswind from the hotline, and H is activity altitude.

$$\rho(DWD,CWD,H) = \frac{1}{(2\pi)^{3/2}\sigma_o^{\,2}\sigma_H} \exp - \frac{1}{2}\left[\frac{DWD^2 + CWD^2}{\sigma_o^{\,2}} + \frac{(H-H_c)^2}{(\sigma_H)^2}\right] \qquad (7)$$

σ_o, σ_H, and H_c determine the initial dimensions of the cloud. The

original empirical fits found these parameters to be:

$$\sigma_o(\text{st.mi}) = \exp\left[0.70 + \frac{\ln Y}{3} - 3.25/(4.0 + (\ln Y + 5.4)^2)\right] \tag{8}$$

$$H_c(\text{KFT}) = 44.0 + 6.1 \ln Y - .205 \left[\ln Y + 2.42\right] \left|\ln Y + 2.42\right| \tag{9}$$

$$\sigma_H = .18\, H_c \tag{10}$$

After extensive calculus and empirical adjustments, shown in part in the WSEG report, downwind (f_d) and crosswind (f_c) transport functions result.

$$f_d = W \cdot NF \cdot F \cdot g(1) \cdot \Phi \left(\frac{L_o \cdot DWD}{L \cdot \alpha_1 \cdot \sigma_d}\right) \tag{11}$$

$$f_c = \frac{1}{(2\pi)^{\frac{1}{2}} \sigma_c} \exp - \tfrac{1}{2} \left(\frac{CWD}{\alpha_2 \sigma_c}\right)^2 \tag{12}$$

W = Total yield in kilotons

NF = Source normalization factor of 2000 r/hr/kt/st mi^2

F = Fission fraction of the device

AF = Fraction of the fireball's lower hemisphere intersecting the earth's surface

g(1) = the deposition function

$\Phi(x)$ = the cumulative normal function of (x)

$L = (L_o^2 + 2\sigma_d^2)^{\frac{1}{2}}$

$\sigma_d^2 = \sigma_o^2 (L_o^2 + 8\, \sigma_o^2)/(L_o^2 + 2\, \sigma_o^2)$

$\alpha_1 = 1/\left[1 + (.001\, H_c \cdot EFW)/\sigma_o\right]$

$\sigma_c^2 = \sigma_o^2 + \frac{1}{L} (8|DWD + 2\, \sigma_d|\, \sigma_o^2) + \frac{2}{L^2} (\sigma_d T_c \sigma_H S_c)^2 + \frac{1}{L^4}$
$((DWD + 2\, \sigma_d) L_o T_c \sigma_H S_c)^2$

S_c = Wind shear component

This model uses a wind shear over the vertical extent of the cloud.

The shear component (S_c) is the change in the wind component normal to the effective wind within the cloud divided by the cloud thickness. It is entered in mph/kft of cloud thickness. No downwind shear is used in the model.

The normalized unit reference dose rate, in roentgens per hour, at the point (DWD,CWD), is the product of the downwind and crosswind transport functions.

$$\dot{D}_{H+1}(DWD,CWD) = f_c \cdot f_c \tag{13}$$

The $T^{-1.2}$ decay approximation is applied to the activity in its transit downwind.

An effective biological dose is also determined. This dose, which is assigned a multitude of names in the literature, will be referred to as simply the biological dose. The dose calculation assumes that ten percent of the dose received is not repairable and that the remaining ninety percent is repairable with the damage decaying over a thirty day time constant.

The biological dose is approximated from the following expression.

$$\text{Bio Dose} \approx \exp - \{.287 + .52 \ln \frac{T_a}{31.6} + .4475 \ln (\frac{T_a}{31.6})^2\} \tag{14}$$

T_a is the average fallout arrival time. The expression is obtained by integrating the unit reference dose rate from the time of arrival.

$$D(t) = 10\% \int_{T_a}^{t} \dot{D}_{H+1}\, \tau^{-1.2} d\tau + 90\% \int_{T_a}^{t} \dot{D}_{H+1}\, \tau^{-1.2} \exp$$

$$\{(30 \text{ DAYS})(t-\tau)\}\, d\tau \tag{15}$$

Four Fortran subroutines for the WSEG fallout model are reproduced in Appendix C. No main program or provisions for constructing contours are provided since each user's requirements are unique. No conversion

to the metric system is made and the subroutines are presented in their received form. The model's outputs are stored in an array as follows: ARRY(33) is biological dose; ARRY(34) through ARRY(39) relate to special military requirements; ARRY(23) is fallout arrival time; ARRY(32) is $\dot{D}_{H+1}$. Additional user instructions appear as comments in each subroutine.

In this study, the three empirically determined parameters are recomputed on the basis of more complete experimental data and on DELFIC calculations to update the information from the original four early test shots. These three are: H_c, the height of the cloud's center; σ_H, the vertical standard deviation of the activity distribution in the cloud; and σ_o, the initial value of both σ_d and σ_c which determine the horizontal extent of the cloud.

New values for these three parameters are developed in Part IV. The effects of these new values on the WSEG model are presented in the comparative model analysis of Part V.

IV. Improvements to the WSEG Fallout Model

Previous evaluations of fallout models have recognized that the WSEG nuclear cloud's height and dimensions are inconsistent with information which is more complete and current than the four early test shots used to empirically fit WSEG (Ref 1:93; 3:29). In addition, Norment has recently proposed that the deposition rate function, g(t), requires updating (Ref 2:86). In the original WSEG-10 report published in 1959, Pugh and Galiano stated that their empirical values are based on limited data and that they should be revised when improved information becomes available (Ref 5:17). However, except for a minor adjustment to the empirical T_c in a WSEG-10 supplement, this author could locate no correction or refinement to the values assigned to the empirical parameters in the original report. Therefore, this study updates the cloud parameters by using more current information.

Four different sources of information for the cloud parameters were evaluated for use. Recognizing the merits and limitations of each source made it necessary to quantitatively evaluate each parameter from each source independently.

The first set of cloud parameters chosen for evaluation were the values of the original WSEG model. Although the cloud was known to be too low and dimensionally in error, it was selected as a basis of comparison for all parametric changes.

The second source of cloud information was data from a series of reports following completion of all atmospheric testing. These reports were prepared by the old Defense Atomic Support Agency (DASA). Many of the cloud parameter curves in these reports are simple empirically

based extrapolations using power functions of yield. Much of the data is based on visual observations. All data used from these reports was extracted from Ref 2 by Norment. For simplicity, all information from these reports will be called DASA data.

The third source of cloud information used was Effects of Nuclear Weapons, ENW (Ref 6:431). The ENW cloud parameters result from an empirically based atmospheric model.

The DELFIC model was the final source evaluated for use. The recently revised Atmospheric Sciences Associates' version of DELFIC was used for all DELFIC information appearing in this study. All dose and dose rate predictions by the original and updated WSEG models are compared to DELFIC predictions.

In selecting the best parametric fits, the most emphasis was placed on the range of accumulated dose from approximately fifty rads to about two thousand rads. This range is important to the user studying the multiple burst scenario as well as to the civil defense planner involved in shelter studies. The stem fallout predictions of DELFIC were ignored. Prediction curves in the region of lethal prompt effects were also ignored. All study was limited to the range of yield from one kiloton to thirty megatons. The low-yield region of highest DELFIC credibility was studied most closely.

The Cloud Thickness Correction

The original WSEG model uses a cloud thickness of $4\sigma_H$ where σ_H = $0.180\ H_c$. Norment has recently recommended that a $\sigma_H = 0.125\ H_c$ would be more consistent with experimental data from DASA (Ref 2:84). Cloud thickness, using both $0.125\ H_c$ and $0.180\ H_c$, was plotted versus yield for the ENW and WSEG models' cloud heights. DELFIC thickness from the

cloud rise module was also plotted on these same graphs which appear as Figures 1 and 2. Observe the exceptional agreement, using .125 H_c, for all three curves at the lower yields. The original WSEG value of 0.180 H_c is not consistent with either DELFIC or ENW models. Although the 0.125 H_c value is recognized as an improvement to the original value of .180 H_c, both values will be evaluated in correcting the other parameters.

The Cloud Height Correction

In empirically determining the height of the cloud center, Pugh and Galiano used the base of the visual cloud as the center of the active cloud (Ref 5:24). This is now known to be too low. The top of the WSEG cloud is 1.36 H_c, using σ_H = 0.180 H_c, and 1.25 H_c using the improved σ_H = 0.125 H_c. These are plotted in Figures 3 and 4 respectively. Also plotted are the DELFIC, DASA, and ENW cloud tops. Several test shots' visible tops are also included (Ref 1:85). Since these shots in the IVY series were under atypical conditions, with coral and water drawn into the cloud, they are presented merely for informative purposes (Ref 1:85).

Note the tendency for the visually based DASA cloud top to be excessively high at most yields. Up to about five megatons, the DELFIC and ENW models' cloud tops agree exceptionally well. Above that, DELFIC's cloud top exceeds all other predicted and observed tops. This excessive cloud height is consistent with Norment's finding that DELFIC underpredicts activity at the higher yields (Ref 3:5). This divergence of DELFIC's cloud top, as well as its thickness, at the higher yields is due to the DELFIC cloud rise module's treatment of the vertical extent of the cloud as a point within the atmosphere. The known tendency of the WSEG cloud to be low is most apparent only at the higher yields when the top, rather than the center, of the clouds are compared.

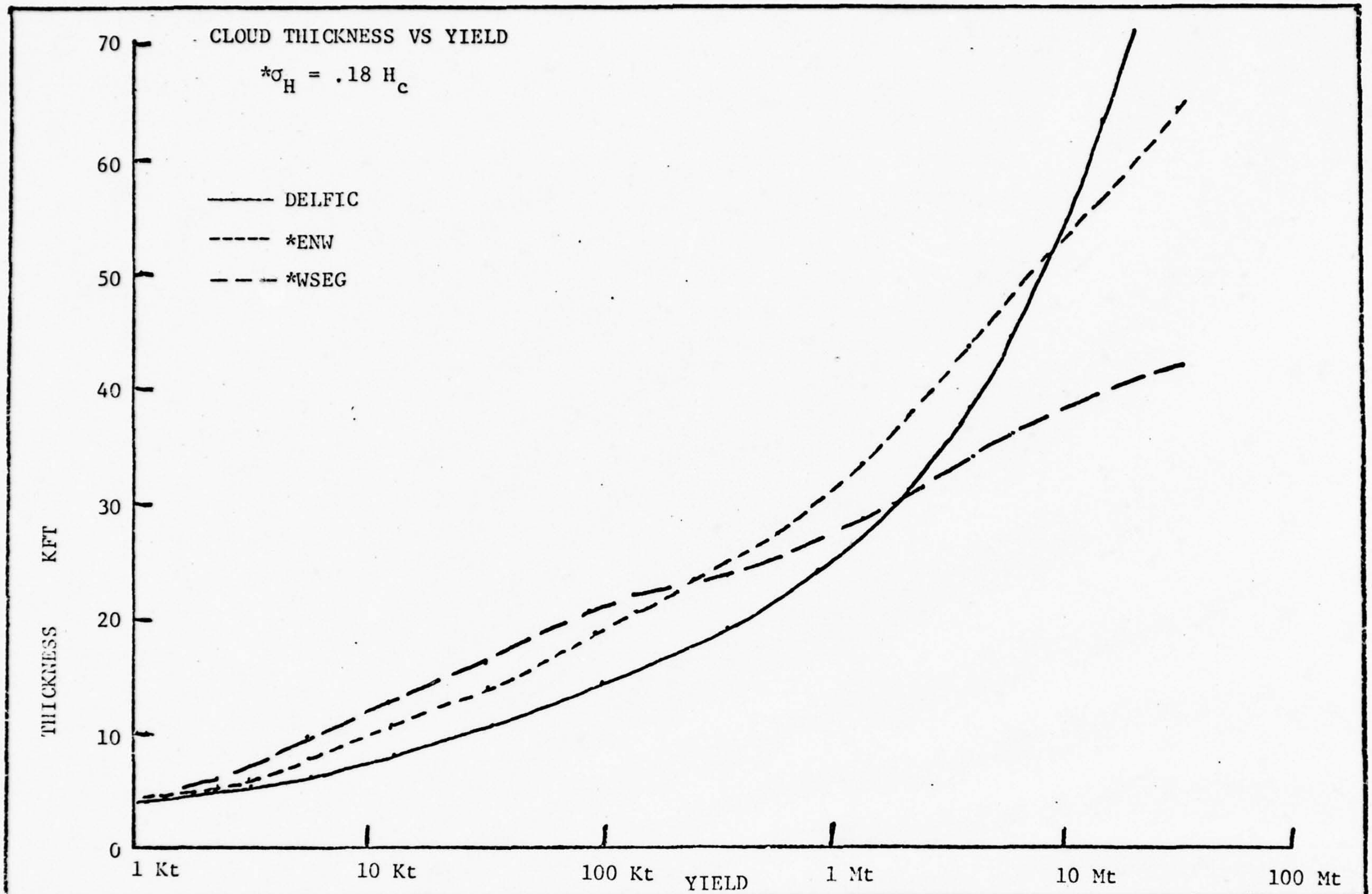

Figure 1. Cloud Thickness vs Yield for $\sigma_H = .18\ H_c$

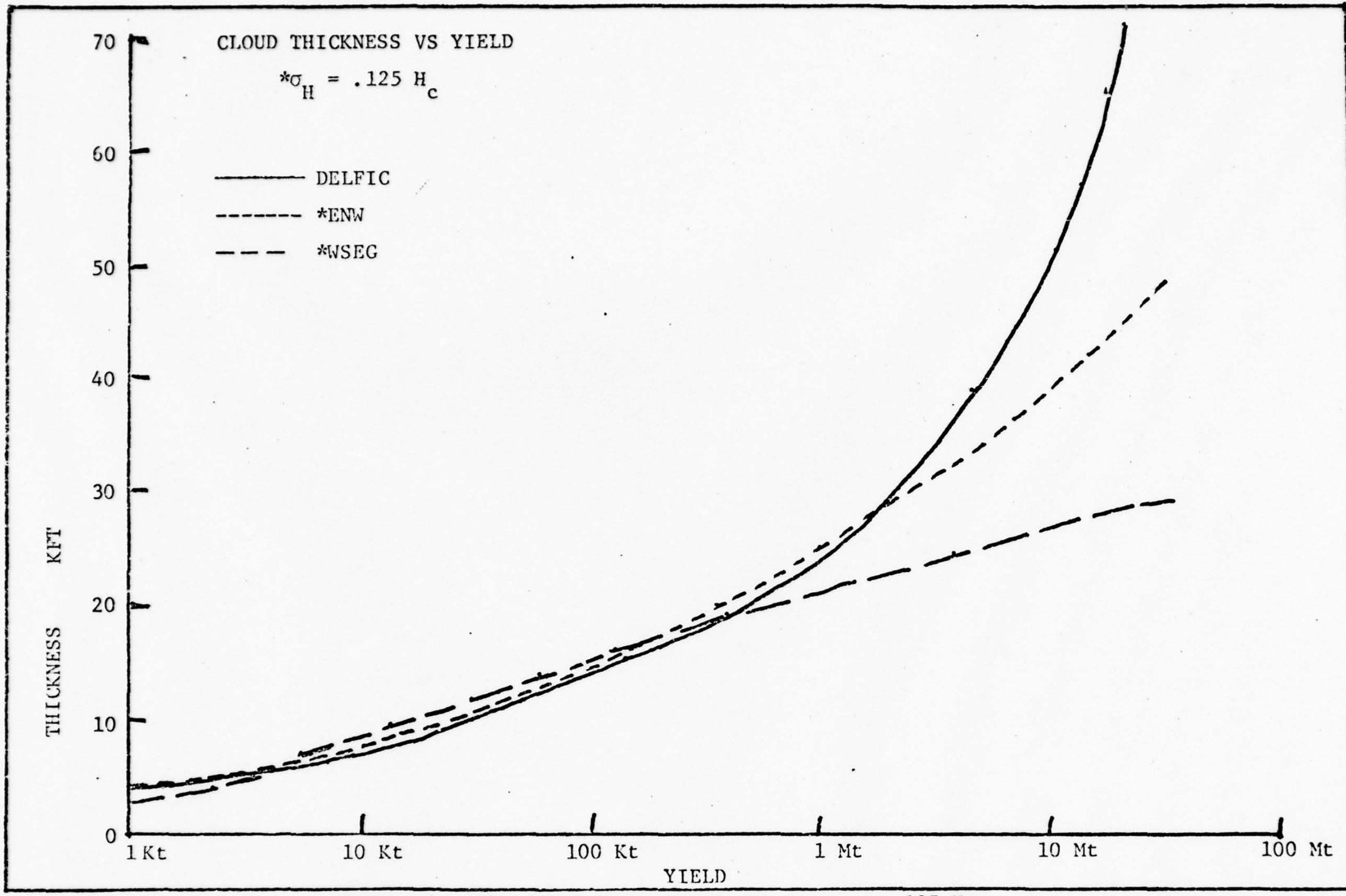

Figure 2. Cloud Thickness vs Yield for $\sigma_H = .125\ H_c$

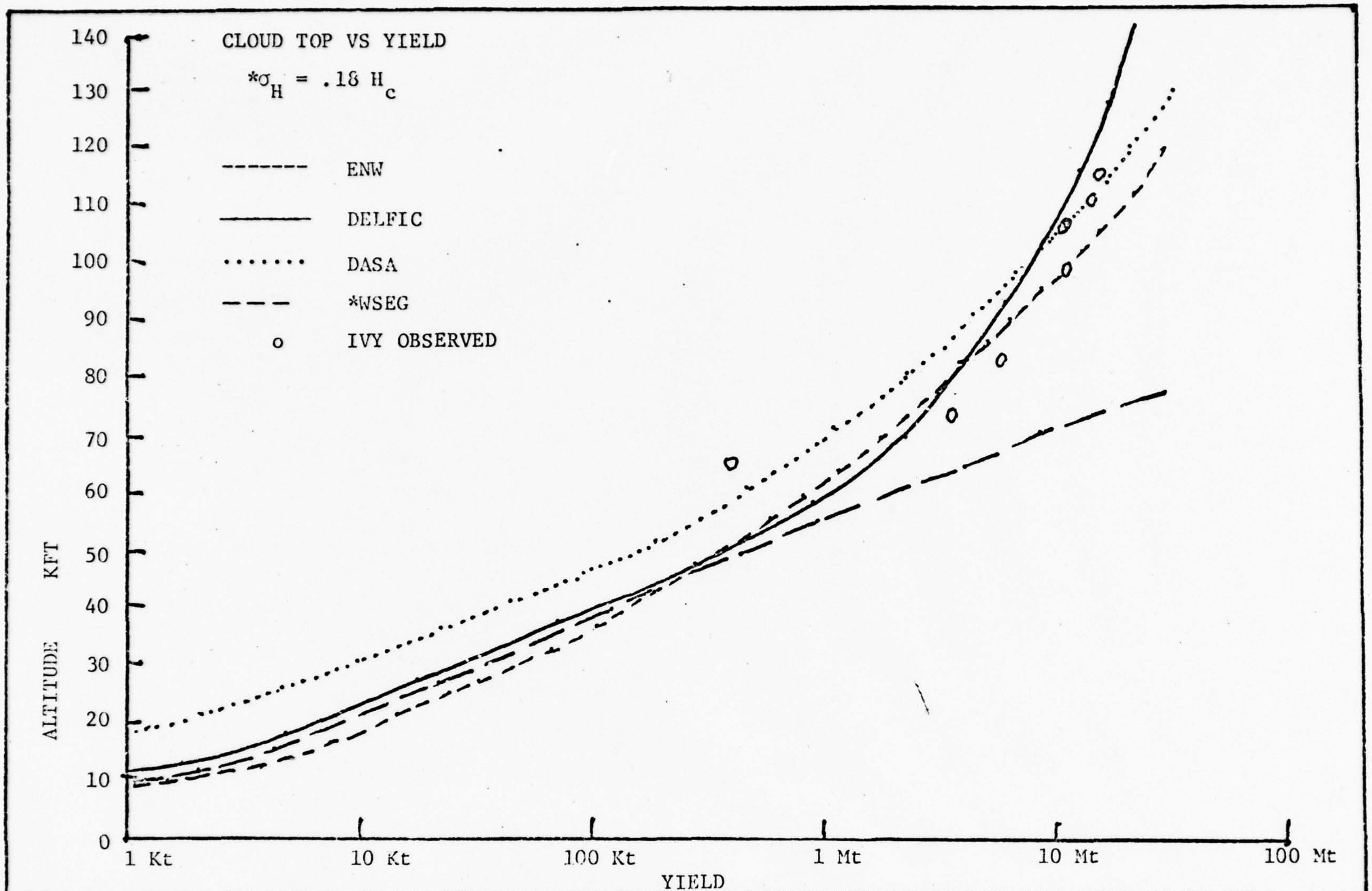

Figure 3. Cloud Top vs Yield for $\sigma_H = .18\ H_c$

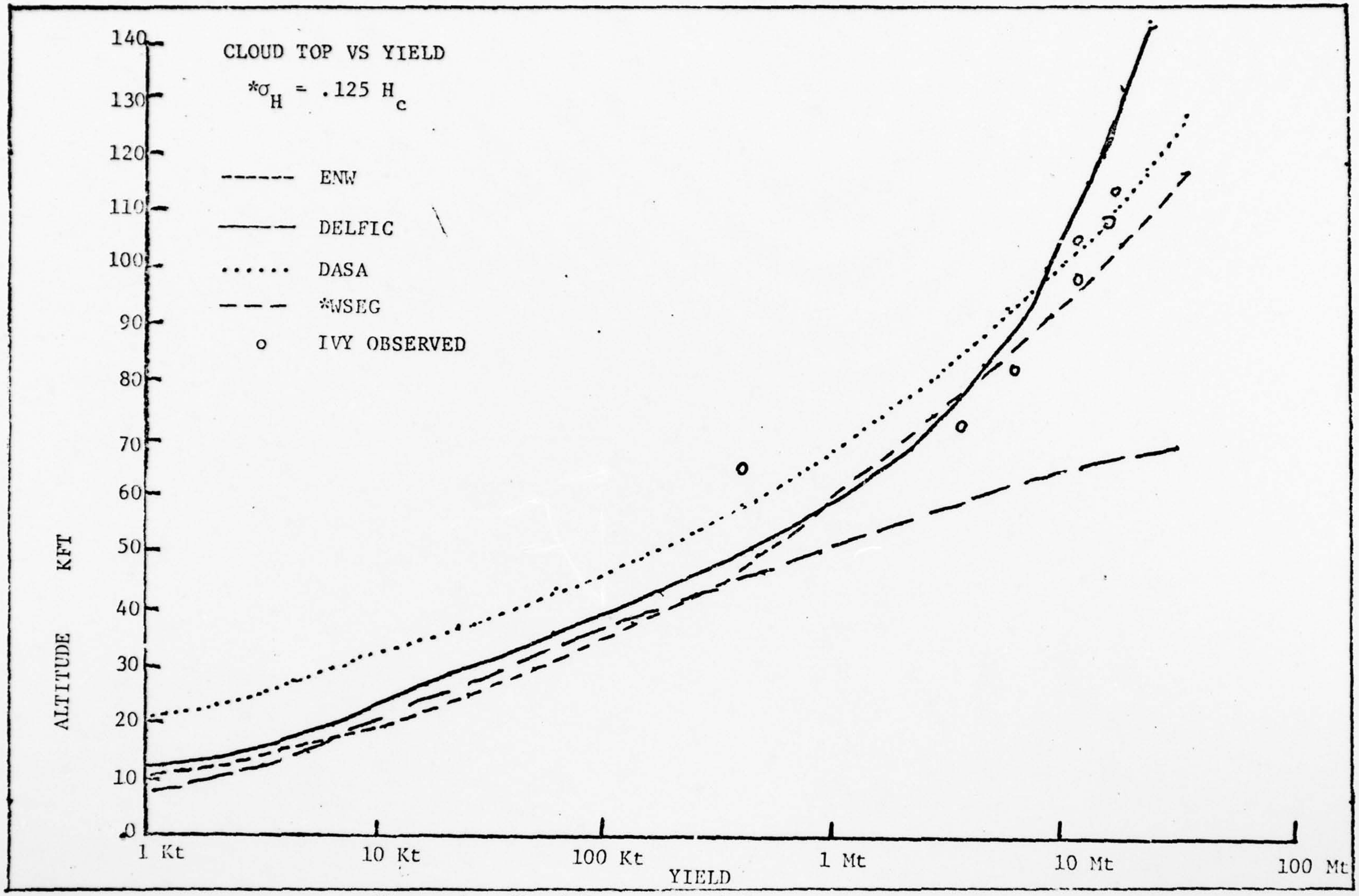

Figure 4. Cloud Top vs Yield for $\sigma_H = .125\ H_c$

Based on the preceeding discussions and on Figures 3 and 4, it initially appeared that the ENW model cloud top provides the best cloud top information. Before this was adopted for use, however, the DASA, ENW, and original WSEG cloud tops were tested in the model. They were tested using both σ_H of .180 H_c and σ_H of .125 H_c.

The H_c for the DASA and ENW cloud tops were determined by setting the cloud top value for each equal to 1.36 H_c for σ_H = .18 H_c and equal to 1.25 H_c for σ_H = .125 H_c. All four H_c values were computed and plotted versus yield. Then, the four were least squares fit to calculational algorithms. The resultant algorithms are:

DASA DATA, $\sigma_H = .18\ H_c$

$$H_c(\text{KFT}) = 53.0 + 19.1 \log_{10}Y + 3.40(\log_{10}Y)^2 + 1.40(\log_{10}Y)^3 + .30(\log_{10}Y)^4 \quad (16)$$

DASA DATA, $\sigma_H = .125\ H_c$

$$H_c(\text{KFT}) = 57.7 + 20.8 \log_{10}Y + 3.70(\log_{10}Y)^2 + 1.40(\log_{10}Y)^3 + .30(\log_{10}Y)^4 \quad (17)$$

ENW MODEL, $\sigma_H = .180\ H_c$

$$H_c(\text{KFT}) = 46.6 + 18.8 \log_{10}Y + 3.20(\log_{10}Y)^2 + 2.20(\log_{10}Y)^3 + .60(\log_{10}Y)^4 \quad (18)$$

ENW MODEL, $\sigma_H = .125\ H_c$

$$H_c(\text{KFT}) = 50.7 + 20.4 \log_{10}Y + 3.50(\log_{10}Y)^2 + 2.40(\log_{10}Y)^3 + .60(\log_{10}Y)^4 \quad (19)$$

Each of the four H_c values were then inserted into the WSEG model with the appropriate σ_H.

Accumulated doses were calculated using the DASA data and ENW model H_c values with σ_H of .125 H_c and .180 H_c. The algorithms were tested from one kiloton to thirty megatons of yield and compared to DELFIC predictions. Typical results are seen in Figures 5 and 6. The original WSEG model is also plotted in those figures. It was observed that as the yield increased through 500 kilotons, the effects of the changes to vertical geometry resulted in minimal changes to predictions.

Throughout the yield range considered, the DASA H_c algorithm tended to underpredict close-in activity and overpredict activity further downwind. This is consistent with its excessive cloud height in Figures 3 and 4. This finding supports Russell's early work which concluded that visual cloud observations do not necessarily reflect active cloud parameters (Ref 1;93). Therefore, the DASA information was rejected for the new H_c determination.

The original WSEG and DELFIC model cloud tops were rejected for use because of the arguments presented previously.

Throughout the yield range, it was seen that the ENW model's H_c with σ_H = .125 H_c consistently predicted fallout contour lengths which were shorter, thus conforming better to DELFIC predictions, than did the ENW model with σ_H = .18 H_c. Thus, the initial conclusion, that using the ENW model cloud top with a σ_H = .125 H_c is the best available correction to the vertical cloud parameters, was confirmed as correct.

The updated algorithm for the height of cloud center is:

$$H_c(\text{KFT}) = 50.7 + 20.4(\log_{10}Y) + 3.50(\log_{10}Y)^2 + 2.40(\log_{10}Y)^3 + 0.60(\log_{10}Y)^4 \qquad (20)$$

The corrected σ_H = .125 H_c. This corrected vertical geometry was

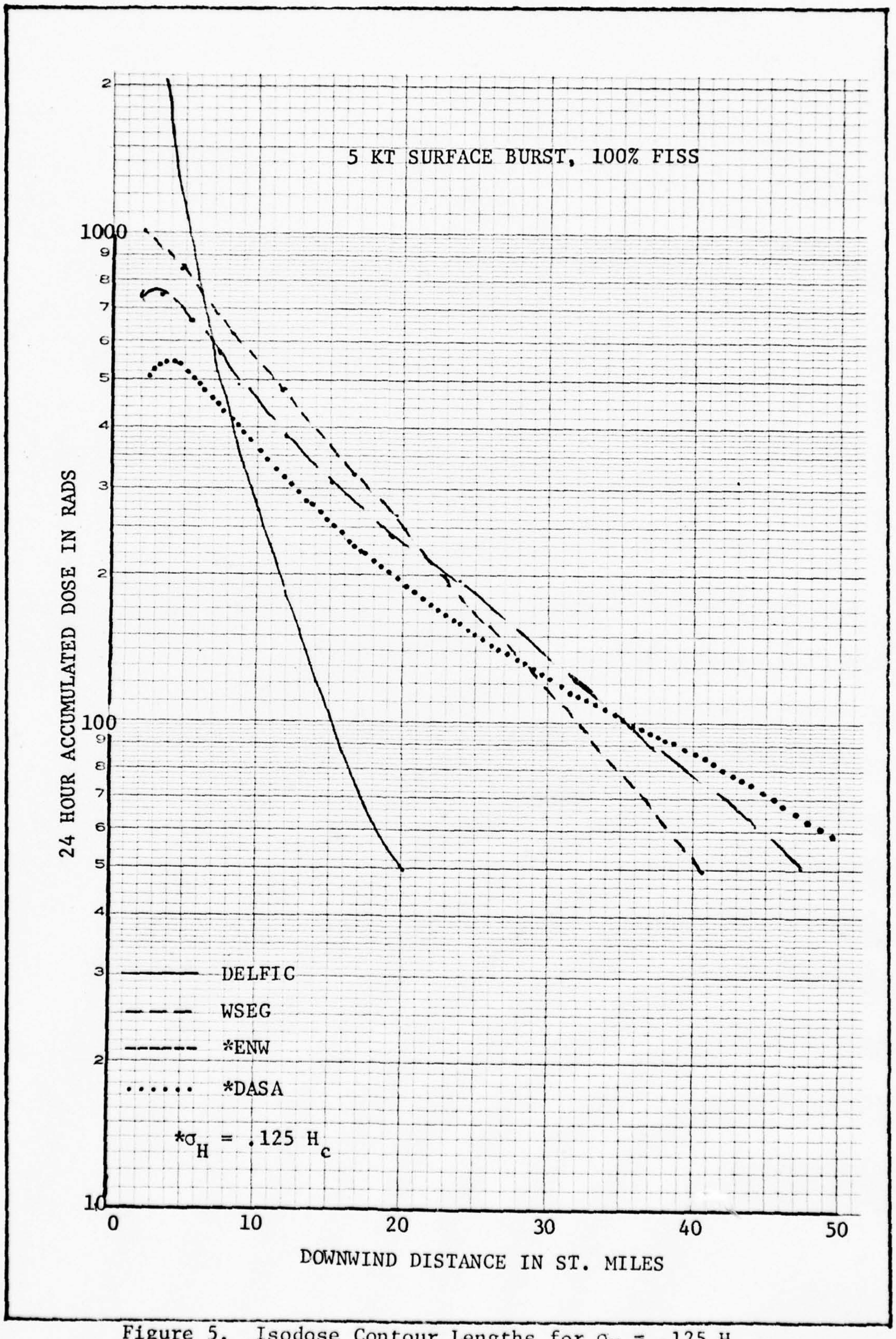

Figure 5. Isodose Contour Lengths for σ_H = .125 H_c

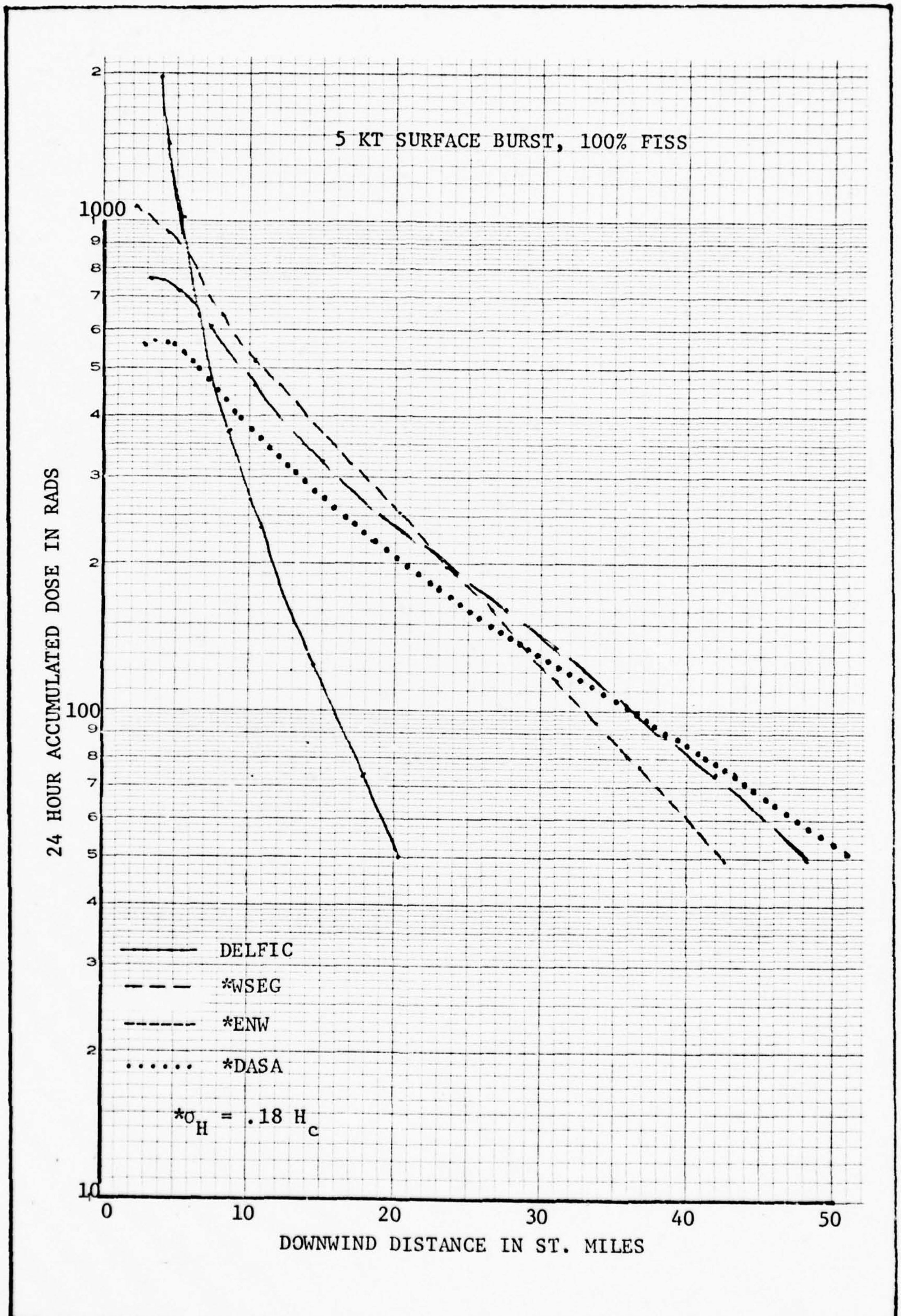

Figure 6. Isodose Contour Lengths for $\sigma_H = .18\ H_c$

incorporated into the WSEG model.

The Cloud Radius Correction

Since Russell has shown that the visual cloud radius observed in test shots does not accurately describe the active radius of the cloud, DELFIC radius was used exclusively in updating the WSEG model's radius (Ref 1:93). Figure 7 shows stabilized cloud radius versus yield for DELFIC and for WSEG. The DELFIC radius plotted is the radius immediately following stabilization of the top in the cloud rise module. Consideration was given to using the laterally stabilized DELFIC radius, but that radius resulted in insignificant changes to predictions at and below 100 kilotons. Above 100 kilotons, the fallout contours were grossly widened and reduced in length. Those wider and shorter contours are more consistent with DELFIC results at the higher yields, but DELFIC has been validated only up to fifty kilotons and is known to under-predict at the higher yields. In addition, it has been found that WSEG radius is excessively small only at lower yields and is adequate at high yields. Figure 7 shows that the vertically stabilized DELFIC cloud radius used is in good agreement with that result.

From one kiloton to thirty megatons, a multiplying factor for WSEG radius was calculated. Multiplying WSEG radius by the factor results in the DELFIC radius value. This multiplying factor, called AK, was then plotted versus yield and also appears in Figure 7. AK was fit by least squares into a yield dependent algorithm.

$$AK = .90 - .40 \log_{10}Y + .30(\log_{10}Y)^2 + .10(\log_{10}Y)^3 \qquad (21)$$

Multiplying the σ_o in the WSEG model by AK corrects WSEG radius to agree with DELFIC radius. Use of the AK multiplying factor results in a maximum deviation of corrected WSEG radius from DELFIC radius of 16% in the

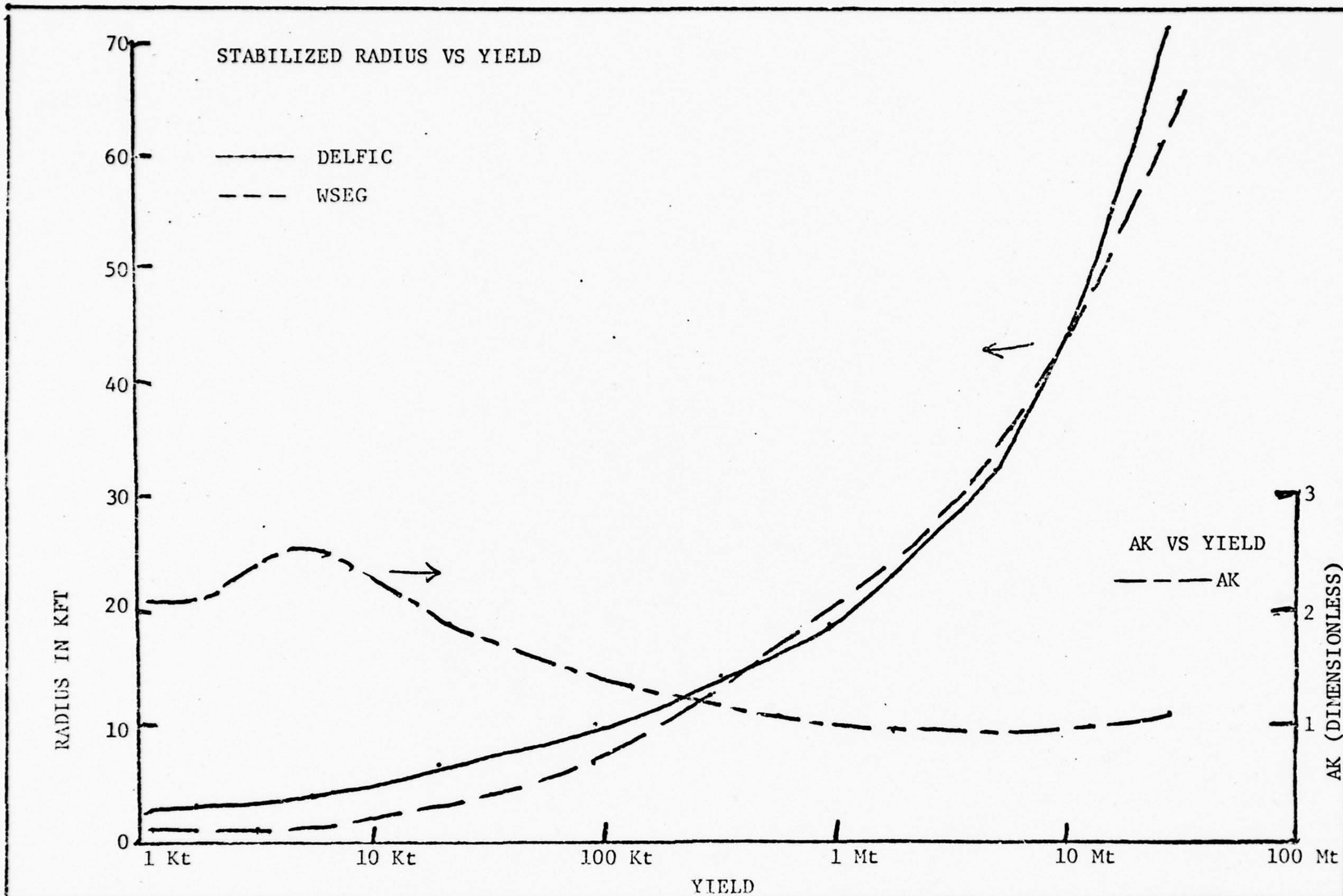

Figure 7. Stabilized Radius vs Yield

two megaton region. Higher and lower yield regions remain well below that deviation.

The data studied in this section and the comparative model analysis of the following section show that the WSEG model is more sensitive to changes in horizontal geometry, or radius, rather than to changes in vertical geometry.

The three empirical changes made to the WSEG model in this section were incorporated into the Fortran version of the model in Appendix C. The revised Fortran subroutine FALLY is presented in Appendix D.

V. Comparative Model Analysis

The original WSEG and corrected WSEG models are both compared to DELFIC. The twenty four hour, and some four hour, accumulated doses along the downwind hotline are plotted versus distance. Typical low and high yield results are seen in Figures 8 and 9. Additional data appears in Appendix E. Note how the WSEG model's excessively long iso-dose contours are shortened significantly at low yields. For example, at 5 kilotons, the 100 rad 24 hour contour line is reduced from 35 miles downwind for the WSEG model to only 20 miles for the updated model. This is close to the DELFIC length of 16 miles. When each model's errors are considered, the DELFIC and updated WSEG curves are in very good agreement outside of the stem fallout region. This good correlation between the updated model and DELFIC is observed through the range of maximum DELFIC validity, one through fifty kilotons. Above that, the updated and original WSEG models both exceed DELFIC predictions. Note that in the 100 to 200 kiloton yield range, the updated model lies between the DELFIC and WSEG predictions. Qualitatively, this compares favorably to the results of test shot Koon. WSEG overpredicts Koon and DELFIC underpredicts it (Ref 3:5). In general, DELFIC tends to under-predict at the higher yields. Figures 1 and 5 support this conclusion when the effects of excessive cloud height and thickness are considered.

At and above 500 kilotons, the predictions of the corrected and original WSEG models are virtually indistinguishable within the bounds of model accuracy up to about 10 megatons. Note the effect of the differences in radius between the original and improved models in the one to ten megaton range. These radius effects cause the predictions

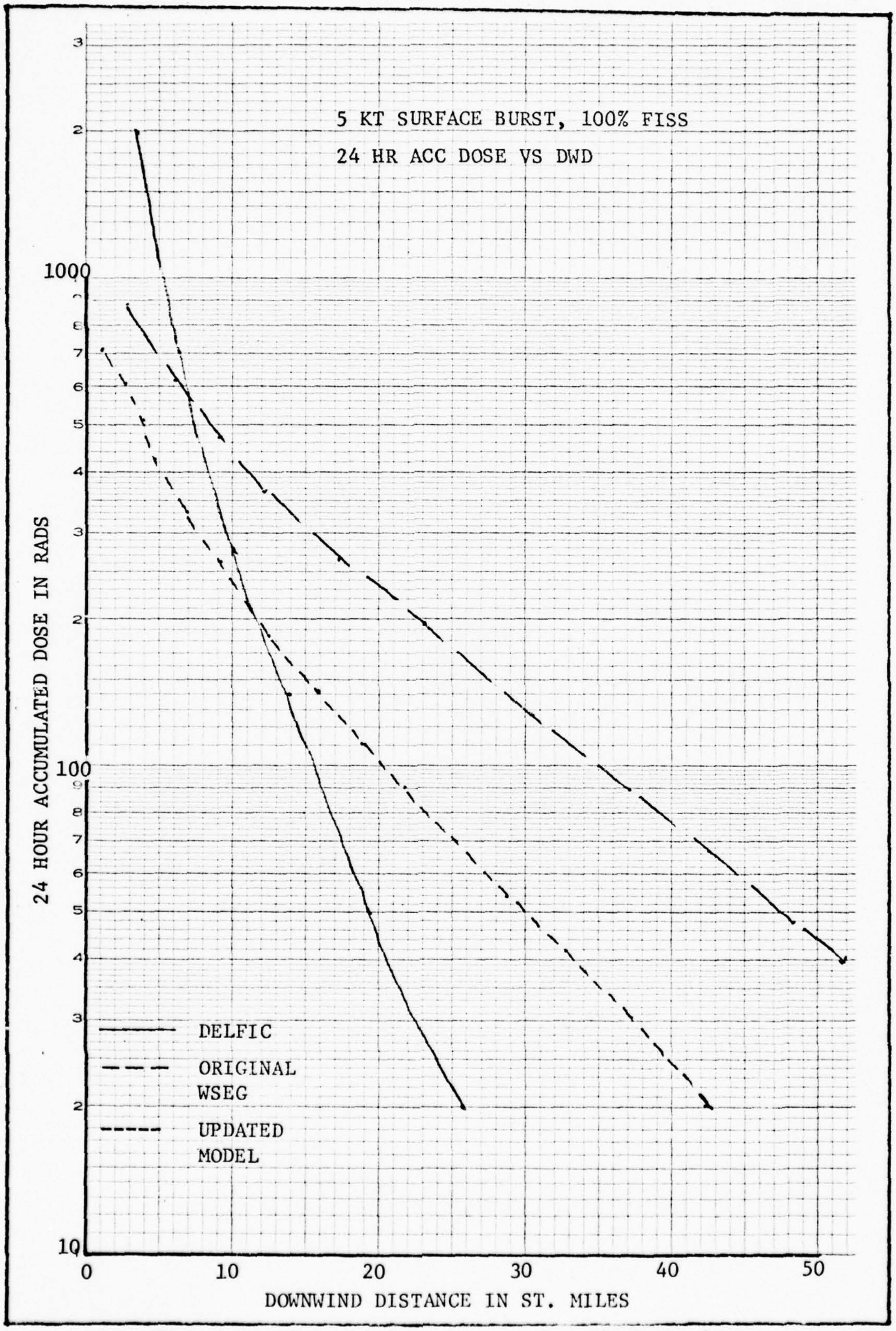

Figure 8. 5 Kt Isodose Contour Length Comparison

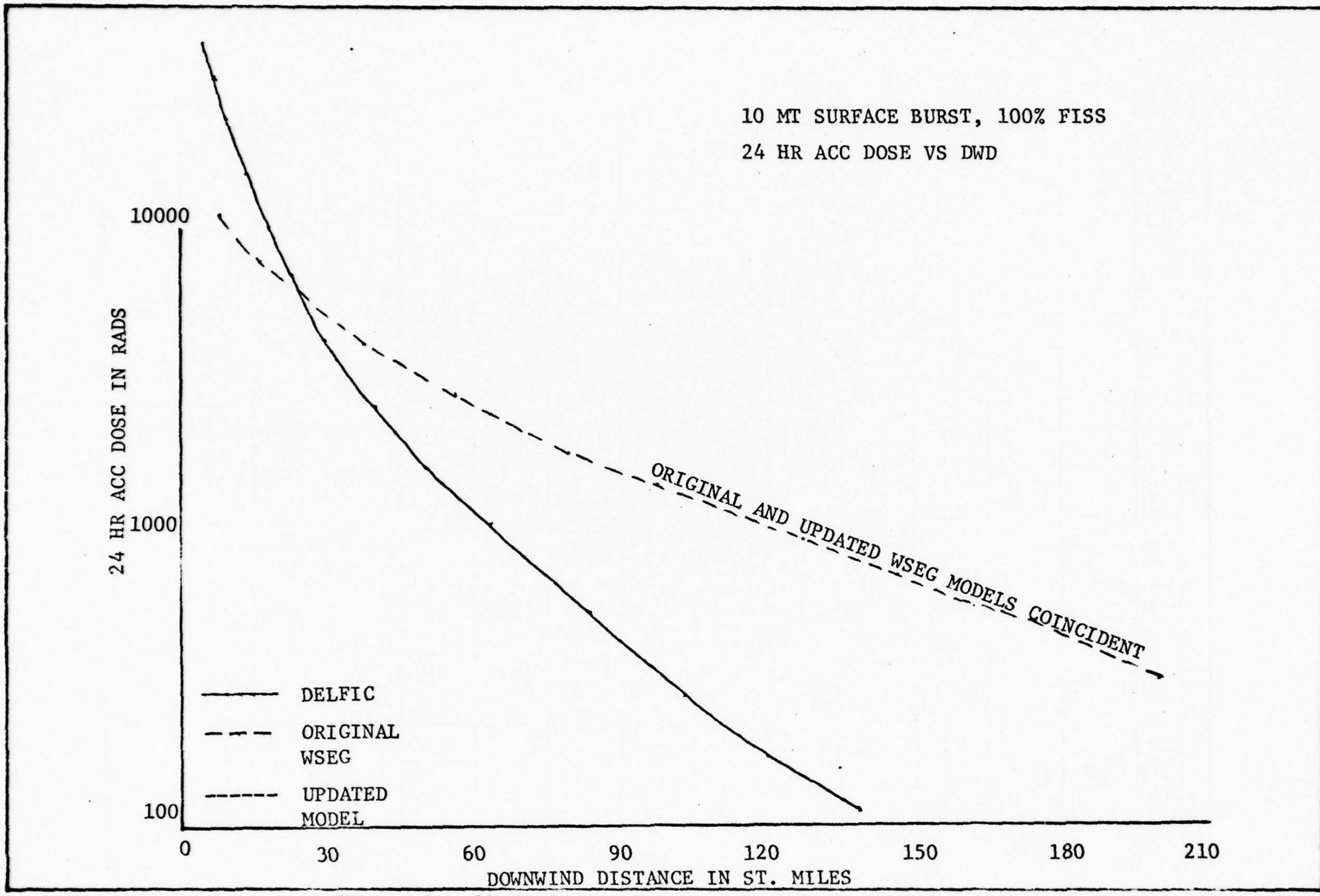

Figure 9. 10 Mt Isodose Contour Length Comparison

of the updated model to exceed those of the original model only in this area. The sensitivity of the model to radius changes can be seen by comparing Figure 7 to the Appendix E data and the crosswind comparison charts of Appendix F. Above 10 megatons, the updated model again tends to shorten and widen the fallout contours consistent with Figure 7.

The effects of the updated cloud geometry on contour width are seen in Figures 10 and 11. Additional data is given in Appendix F. Note, in Appendix F, that the updated model consistently predicts wider contours than the original model does at all yields where WSEG has been critiqued as having contour lines which are too narrow.

At low yields, where DELFIC has been shown to be most valid and where WSEG has been shown to be most unreliable, the shortened and widened contours of the corrected model more closely resemble DELFIC predictions, which have been shown to best model actual experimental data, than the contours of the original WSEG model do. (Ref 3)

Above 50 kilotons, quantitative assessment of the improved model is not feasible due to the lack of test data under such conditions and the lack of an experimentally validated comparison model at the higher yields. The divergence of the updated model's radius, and therefore contour widths, from DELFIC and original WSEG in the two to ten megaton range is therefore considered as inconsequential when compared to the confirmed improvements made at the low yields where the improvement can be quantified and validated.

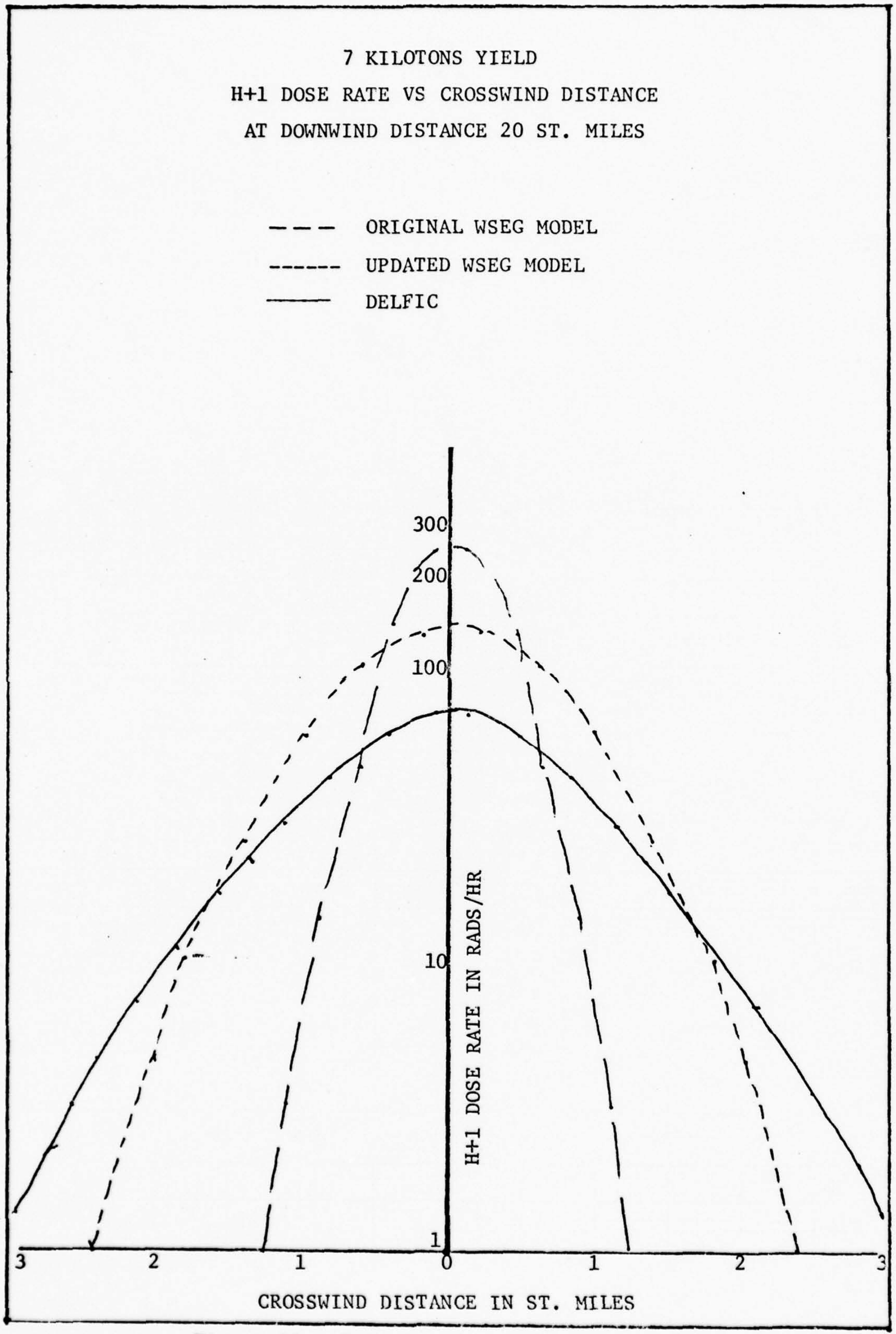

Figure 10. 7 Kt Isodose Width Comparison

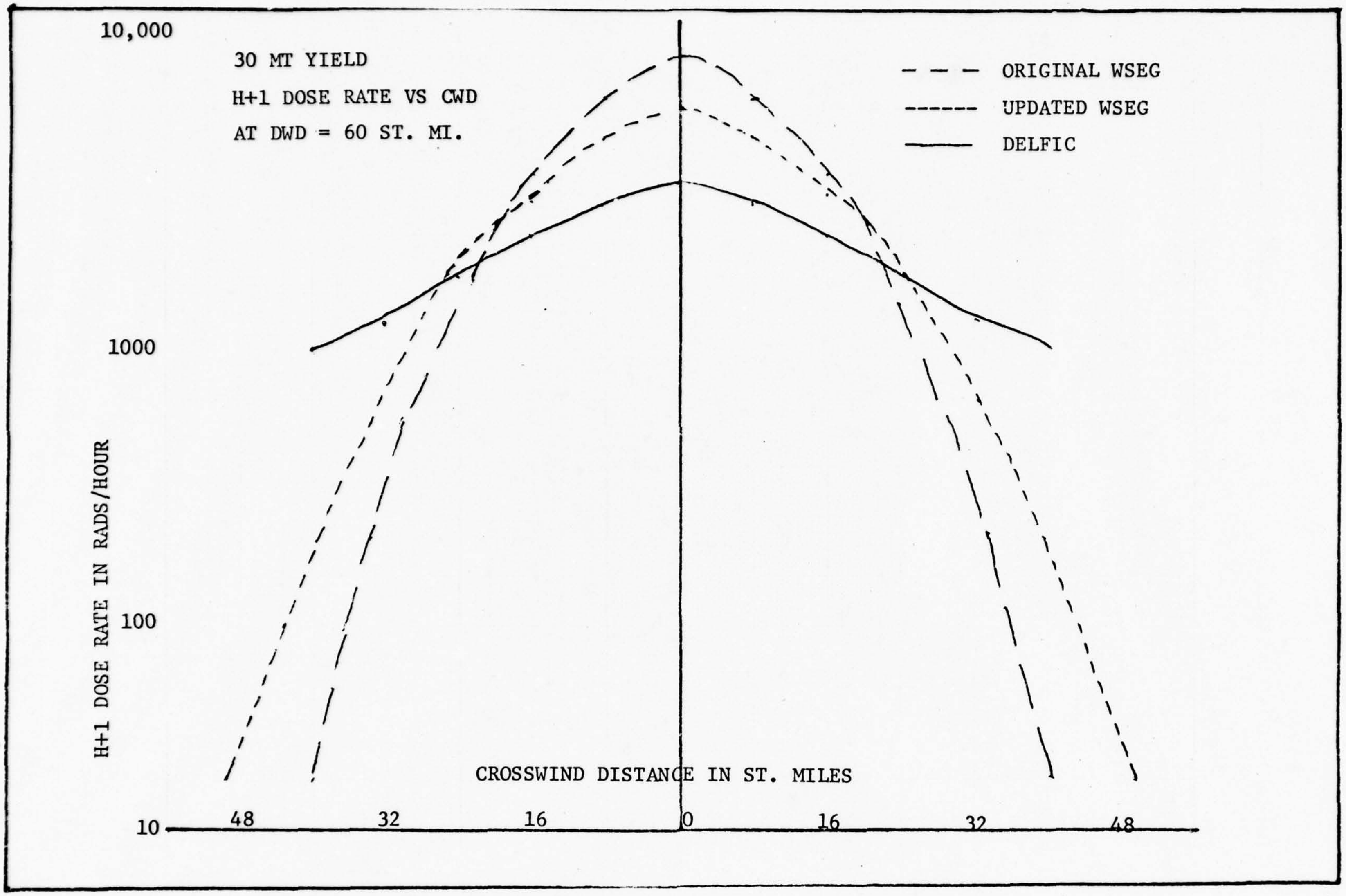

Figure 11. 30 Mt Isodose Width Comparison

VI. Conclusions and Recommendations

By correcting the nuclear cloud's dimensions and height, the WSEG fallout model's prediction capability at yields below 500 kilotons has been significantly improved. In this age of radically improved inertial guidance systems, MIRV for ICBM and SLBM, the extremely accurate cruise missile, and reduced emphasis on the manned penetrating bomber, it can be expected that the strategic planner will place future emphasis on highly accurate, lower yield weapons for optimum utilization of his available throw weight and weapon material. Thus, the improvements made to the WSEG model are highly relevant to the yield range of most practical interest. Therefore, the effects of the geometrical changes and their calculational algorithms to WSEG in the multi-megaton range, which cannot be quantitatively evaluated by either typical experimental data or by a verified prediction model, will be considered as being of merely pedagogical interest.

The corrected model's improved prediction capability at the low dose levels, below 500 rads accumulated, is highly applicable to the scenario of many low yield, highly accurate weapons detonated in a target area rather than one or a few high yield weapons. Any overprediction, as is done by the original WSEG model, in the total (from all weapons) dose accumulated range of 300 to 600 rads can grossly exaggerate casualty predictions. Very small, relative, overpredictions in the LD/50 region around 450 rads accumulated can cause disproportionate overprediction of casualties. Russell has proposed that WSEG, in an earlier version, could conceivably overpredict fatalities by one to two orders of magnitude (Ref 1:210).

This study recommends that users of the WSEG fallout prediction model make three changes to it. The height of the cloud center, H_c, should be corrected. The current model's cloud center height is given by:

$$H_c(\mathrm{KFT}) = 44 + 6.1\ \ln Y - .205(\ln Y + 2.42)\ |\ln Y + 2.42| \qquad (22)$$

This should be changed to:

$$H_c(\mathrm{KFT}) = 50.7 + 20.4\ \log_{10}Y + 3.50(\log_{10}Y)^2 + 2.40(\log_{10}Y)^3 + .60(\log_{10}Y)^4 \qquad (23)$$

This correction is seen as ARRY(3) in Appendix D, the corrected subroutine FALLY. The cloud thickness correction is made by changing σ_H from a value of .180 H_c to .125 H_c. This σ_H is ARRY(4) in Appendix D. The radius correction is made by multiplying the σ_o, or ARRY(1), by a yield dependent adjustment factor, AK in Appendix D.

$$AK = .90 - .40\ \log_{10}Y + .30(\log_{10}Y)^2 + .10(\log_{10}Y)^3 \qquad (24)$$

By making these three changes to the original WSEG model, the WSEG user can significantly improve prediction capability below 500 kilotons.

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Appendix A

List of Terms and Abbreviations

This appendix provides the reader who is not familiar with the nomenclature used in this study with a list of common terms and abbreviations used herein.

AFIT	Air Force Institute of Technology
DELFIC	Department of Defense Land Fallout Prediction System
$\dot{D}_{H+1}$	Unit Reference Dose Rate. Gives activity at detonation plus one hour counting all fallout that has arrived at and is in transit to the point of interest.
ENW	EFFECTS OF NUCLEAR WEAPONS, widely used reference by S. Glasstone and P. Dolan, see reference 6.
ICBM	Intercontinental Ballistic Missile
IVY	Test shot series on Pacific atolls
LD/50	Exposure level in rads defined as the level where essentially 100% fatalities result at twice LD/50 and very few occur at one half the LD/50 dose.
MIRV	Multiple Independently Targeted Re-entry Vehicle
NAS	National Academy of Science
RAD	Radiation absorbed of 100 ergs of ionizing radiation per gram of absorbing material
Roentgen	Dated term approximately equivalent to one rad
SLBM	Submarine Launched Ballistic Missile
WSEG	Weapons Systems Evaluation Group

Appendix B

The DELFIC Model (Ref 4:9-10)

This appendix is presented to provide the reader unfamiliar with the DELFIC fallout prediction model with some general information about the model. Since the model is far too detailed and complex to explain indepth, the model summary by H. Norment, in Reference 4, is given in its entirety.

"DELFIC is a research code which, for practical purposes, is useful only to those who have the time and inclination to become deeply involved in local fallout prediction. It is structured in a physically straightforward manner such as to include, via use of the best practicable models, all of the phenomena that are important to the formation and distribution of local fallout from surface and low airbursts. It is designed for highly flexible usage.

The code uses a dynamic cloud rise model that produces results which are demonstrably superior to those produced by conventional means. This model has the unique advantage of being able to account for the effects of atmosphere structure on the cloud rise and stabilization. Thus, it can made credible predictions for locations that are geographically remote from the test site areas, where all of the observed data have been obtained. (Examples of important remote areas are northern Europe and northern Asia.) Activity calculations are rigorously done such that use of a questionable activity normalization factor (i.e., the K-factor) is not required. Also not required is use of a gross-activity decay equation, such as the conventional $t^{-1.2}$ law.

Transport can be via time and/or space variant wind fields, or it

can follow the practice of all other codes by using a single wind field that varies only in the vertical. Turbulent dispersion is described in Appendix A.4.

Maps of a large number of different properties of the fallout field can be prepared, including some types that are not available from any other code.

In ref. 3 we describe two versions of the code: one used by the Ballistics Research Laboratories (BRL), and an updated, improved version used by Atmospheric Science Associates (ASA). In the ref. 3 study the BRL version was used, but here we use the ASA version.

In the ref. 3 study we found that DELFIC provides adequate predictions for surface and near surface bursts, and we rated it to be the best of the codes studied."

Appendix C

Original WSEG Model Fortran Subroutines

```
INE FALLY        74/74    OPT=1                              FTN 4.6+446         09/13

      SUBROUTINE FALLY(YIELD,FISS,HOB,ARRY)
C     TO COMPUTE THE YIELD DEPENDENT PARAMETERS IN THE WSEG10/-NAS
C     FALLOUT MODEL.   YIELD IS YIELD IN MEGATONS, FISS IS FISSION
C     FRACTION, HOB IS HEIGHT OF BURST IN FEET, ARRY IS AN ARRY OF FORTY
C     ELEMENTS USED TO PRESERVE RESULTS OF DIFFERENT SUBROUTINE CALLS.
C     SUBROUTINES SHOULD BE CALLED IN ORDER OF NEW YIELD, WIND VELOCITY
C     OR WIND SHEAR, DOWNWIND DISTANCE, AND CROSSWIND DISTANCE.
C     THE VALUES IN ARRY(1) TO ARRY(6) ARE FILLED HERE.
      DIMENSION ARRY(1)
      XLNY = ALOG(YIELD)
      TEM=XLNY+5.4
      TEMP=0.70+0.3333333* XLNY-3.25/(4.0+TEM*TEM)
      ARRY (1) = EXP(TEMP)
      ARRY(2) = ARRY(1) *ARRY(1)
      TEMP = XLNY +2.42
C ORIGINAL WSEG/NAS/S/P VERSION
      ARRY (3) = 44.+ 6.1*XLNY -0.205*TEMP*ABS(TEMP)
      ARRY(4)=.18*ARRY(3)
       HCTWO = ARRY(3)/25.
      HCSIX = ARRY(3)/60.
      ARRY(5)=1.0573203*(12.*HCSIX-2.5*HCSIX*HCSIX)*(1.0-0.5*EXP(-HCTWO*
     1HCTWO))
      IF(HOB.GT.0.) GO TO 6
      ARRY(6) = 2000000.*FISS*YIELD
      RETURN
    6 CONTINUE
      XMHB=180.*(YIELD*1000.)**0.4
      IF(HOB.LE.XMHB) GO TO 10
      ARRY(6)=0.
      RETURN
   10 CONTINUE
      TEMP=HOB/XMHB
      AF=0.5*(1.-TEMP)*(1.-TEMP)*(2.+TEMP)+0.001*TEMP
      ARRY(6)=2000000.*FISS*AF*YIELD
      RETURN
      END
```

```
      SUBROUTINE FALLFW(EFW,SC,ARRY)
C     TO COMPUTE THE WIND SPEED OR WIND SHEAR EFFECTS IS THE WSEG 10-
C     NAS FALLOUT MODEL.
C     EFW IS WIND VELOCITY IN STATUTE MILES PER HOUR, SC IS WIND SHEAR
C     IN STATUTE MILES PER HOUR PER KILOFOOT, ARRY IS A STORAGE ARRAY.
C     THE VALUES IN ARRY(7) TO ARRY(13) ARE SUPPLIED HERE.
      DIMENSION ARRY(1)
       XLO = EFW*ARRY(5)
      XLOS = XLO*XLO
      SIGUS=ARRY(2)*(XLOS+8.*ARRY(2))/(XLOS+2.*ARRY(2))
      ARRY(14) = SQRT(SIGUS)
      XLS = XLOS + 2.*SIGUS
      XL = SQRT(XLS)
       ARRY(15) = 6./XL
      ARRY(7)=ARRY(15)*ARRY(2)
      TMPA = ARRY(5)*ARRY(4)*SC
      TEMP = XLO*TMPA/XLS
      ARRY(8) = TEMP*TEMP
      TEMP = ARRY(14) *ARRY(5)*ARRY(4)*SC/XL
      ARRY(9) = ARRY(2) +2.*TEMP*TEMP
      XLOPS = XLOS + 0.5*SIGUS
       ARRY(10) = (XLOS + SIGUS)/XLOPS
      IF(ARRY(10).LT.1.002) GO TO 8
      TM = 1./ARRY(10)
C     GAMMA FUNCTION  APPROX HASTINGS P.156
      GAMMA=1. +TM*(-0.57569867 + TM*(0.97781781+TM*(-0.8235627+TM*(
     10.67399080 + TM*(-0.3282793 + TM*0.07673206)))))
      ARRY(11)=1./(XL*GAMMA)
      GO TO 9
    8 ARRY(11)=1./XL
    9 CONTINUE
      ARRY(17) = 0.001*ARRY(3)*EFW/ARRY(1)
      ALONE = 1./(1. + ARRY(17))
      ARRY(18) = XLO/ (XL*ALONE*ARRY(14))
       ARRY(12) = XLOS *ARRY(5) *ARRY(5)/(XLS*XLOPS)
      ARRY(13) = 0.25 + 2.*SIGUS/XLOPS
      IF(EFW.LT.0.000001) GO TO 5
      ARRY(16) = 2./EFW
      GO TO 6
    5 ARRY(16)=999999999.
    6 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FALLOW(DWD,  MDCAL,TWPN,ARRY)
C     TO COMPUTE DOWNWIND DISTANCE EFFECTS IN THE WSEG 10 - NAS FALLOUT
C     MODEL.
C     DWD IS THE DOWNWIND DISTANCE IN STATUTE MILES, MDCAL = 0-ONLY
C     WSEG BIO DOSE,  1-NMCSSC BIO DOSE AT BHRS, 2-ALSO MAX DOSE,
C     TWPN IS TIME OF WEAPON DETONATION IN HOURS, ARRY IS A STORAGE
C     ARRAY.
C     THE VALUES IN ARRY(20) TO ARRY(31) ARE COMPUTED HERE.
      DIMENSION ARRY(1),BHRS(5)
      DATA BHRS(1),BHRS(2), BHRS(3), BHRS(4), BHRS(5)/
     1 7.,22., 58.,  211., 800./
      TP=DWD+2.*ARRY(14)
      DWP=ABS(TP)
      TMP = ARRY(15) *DWP
      IF(TMP.LE.3.) GO TO 8
      DWP=3./ARRY(15)
    8 CONTINUE
       SIGCS = ARRY(9) + ARRY(7) *DWP + ARRY(8)*TP*TP
      SIGC = SQRT(SIGCS)
      TA = ARRY(16)*DWD
      IF(TA.GT.4.) GO TO 11
C    APPROX HASTINGS P.185 FOR CUM NOR
      TM = ABS(TA/1.414213562)
      TMP = 1. + TM*(0.278393+TM*(0.230389+TM*(0.000972+TM*0.078108)))
      TMP = TMP *TMP
      CUP = 1.-1./(TMP*TMP)
      IF(TA .LT. 0) GO TO 5
      CUV = 0.5*(1. + CUP)
      GO TO 7
6     CONTINUE
      CUV = 0.5*(1. - CUP)
7     CONTINUE
      ALTWO = 1./(1.+ARRY(17)*(1.-CUV))
      GO TO 12
   11 ALTWO=1.
   12 CONTINUE
      ARRY(20)=1./(2.50663*SIGC)
       TMP = ALTWO *SIGC
      ARRY(21) = 0.5/(TMP*TMP)
      TA = DWD *ARRY(18)
      IF(TA.LT.5.) GO TO 14
      CUV=1.
      GO TO 15
   14 CONTINUE
C    APPROX HASTINGS P.187 FOR CUM NOR.
      TM = ABS(TA/1.414213562)
      TMP = 1+TM*(0.0705230784+TM*(0.0422820123+TM*(0.0092705272+TM*
     1(0.0001520143+TM*(0.0002765672+TM*0.0000430638)))))
      TMP=TMP*TMP
      TMP=TMP*TMP
      TMP=TMP*TMP
      TMP=TMP*TMP
      CUP= 1.-1./TMP
      IF(TA .LT. 0) GO TO 21
      CUV = 0.5*(1. + CUP)
      GO TO 22
21    CONTINUE
```

```
      CUV = 0.5*(1. - CUP)
22    CONTINUE
   15 CONTINUE
      IF(ARRY(10).LT.1.002) GO TO 17
       TMP =(ABS(DWD)*ARRY(15)/8.)**ARRY(10)
      GO TO 18
   17 TMP=ABS(DWD)*ARRY(15)/8.
   18 CONTINUE
      IF(TMP.LT.30.) GO TO 19
      ARRY(22) = 0.
      ARRY(23) = 999993.
      ARRY(24) = 1.
      RETURN
19    CONTINUE
      GT =ARRY(11)*EXP(-TMP)
      ARRY(22) = ARRY(5)*GT*CUV
      TMP = ARRY(13) + TP * TP*ARRY(12)
      ARRY(23) = SQRT(TMP)
      TMP = ALOG(ARRY(23)/31.6)
      ARRY(24)= EXP(-(0.287+0.52*TMP+0.04475*TMP*TMP))
      IF(MDCAL .NE. 0) GO TO 31
      RETURN
31    CONTINUE
      TMP = ARRY(23)**(-0.2)
      DO 32 J = 1,5
      JST = 24 + J
      BT = BHRS(J) - TWPN
      BTT = BT - ARRY(23)
      IF(BTT .GE. 0.) GO TO 33
      ARRY( JST) = 0.
      GO TO 32
33    CONTINUE
      ZZ = 0.5 + 4.5*EXP(-(0.00051 + 0.00025*TMP)*(BTT))
      ARRY(JST) =(TMP - (BT**(-0.2)))*ZZ
32    CONTINUE
      IF(MDCAL .NE. 1) GO TO 34
      RETURN
34    CONTINUE
      TMP = 0.
      DO 35 K = 1,5
      KLK = 24 + K
      IF( TMP .GT. ARRY(KLK)) GO TO 35
      TMP = ARRY(KLK)
      KVL = KLK
35    CONTINUE
      IF(KVL .NE. 25) GO TO 36
      ARRY(30) = ARRY(25)
      ARRY(31) = BHRS(1)
      GO TO 39
36    CONTINUE
      IF(KVL .NE. 29) GO TO 37
      ARRY(30) = ARRY(29)
      ARRY(31) = BHRS(5)
      GO TO 39
37    CONTINUE
      YM = ARRY(KVL - 1)
      YO = ARRY(KVL)
      YP = ARRY(KVL + 1)
      DELLT =  0.25*(ALOG(BHRS(5)) - ALOG(BHRS(1)))
      TO = ALOG(BHRS(KVL - 24 ))
      DELP = YP - YO
      DELM = YO - YM
      DELSQ = DELP - DELM
      DELYO = 0.5*(DELP + DELM)
      DT = - DELYO*DELLT/DELSQ
      XLT = TO + DT
      ARRY(31) = EXP(XLT)
      ARRY(30) = YO -  0.5*DELYO*DELYO/DELSQ
39    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FALLOW(CWD,MDCAL,ARRY)
C     TO COMPUTE CROSSWIND DISTANCE EFFECTS FOR THE WSEG 10 -NAS
C     FALLOUT MODEL AND PRODUCE FINAL ANSWERS.
C     CWD IS CROSSWIND DISTANCE IN STATUTE MILES, MDCAL OF 0-ONLY WSEG
C     BIO DOSE, 1-NMCSSC TIME DOSES, 2-ALSO MAX DOSE, ARRY IS A STORAGE
C     ARRAY.
C     FOR OUTPUT THE H + 1 DOSE RATE IS IN ARRY(32), THE WSEG
C     BIOLOGICAL DOSE IS IN ARRY(33), THE TIME OF FALLOUT ARRIVAL
C     AFTER WEAPON BURST TIME IS IN ARRY(23).
C     THE NMCSSC BIO DOSE AFTER 7,22,63,211, AND 800 HOURS FROM THE
C     STRAT OF THE TIME AXIS IS IN ARRY(34) TO ARRY(38). THE MAX
C     BIOLOGICAL DOSE IS IN ARRY(39) AND THE TIME OF MAX DOSE AFTER
C     TIME ORIGIN IS IN ARRY(31).
C     THE VALUES IN ARRY(32) TO ARRY(39) ARE COMPUTED HERE.
      DIMENSION ARRY(1)
      TMP = CWD * ARRY(21)*CWD
      IF(TMP .GT. 30.) GO TO 6
      FC = ARRY(20) *EXP(-TMP)
      ARRY (32) = FC*ARRY(22)
7     CONTINUE
      ARRY(33)= ARRY(32)*ARRY(24)
      IF( MDCAL .NE. 0) GO TO 3
      RETURN
3     CONTINUE
      DO 4 J = 1,5
      ARRY(J + 33) = ARRY(32)*ARRY(J + 24)
4     CONTINUE
      IF(MDCAL .NE. 1) GO TO 5
      RETURN
5     CONTINUE
      ARRY(39) = ARRY(30)*ARRY(32)
      RETURN
6     CONTINUE
      ARRY(32) = 0.
      GO TO 7
      END
```

Appendix D

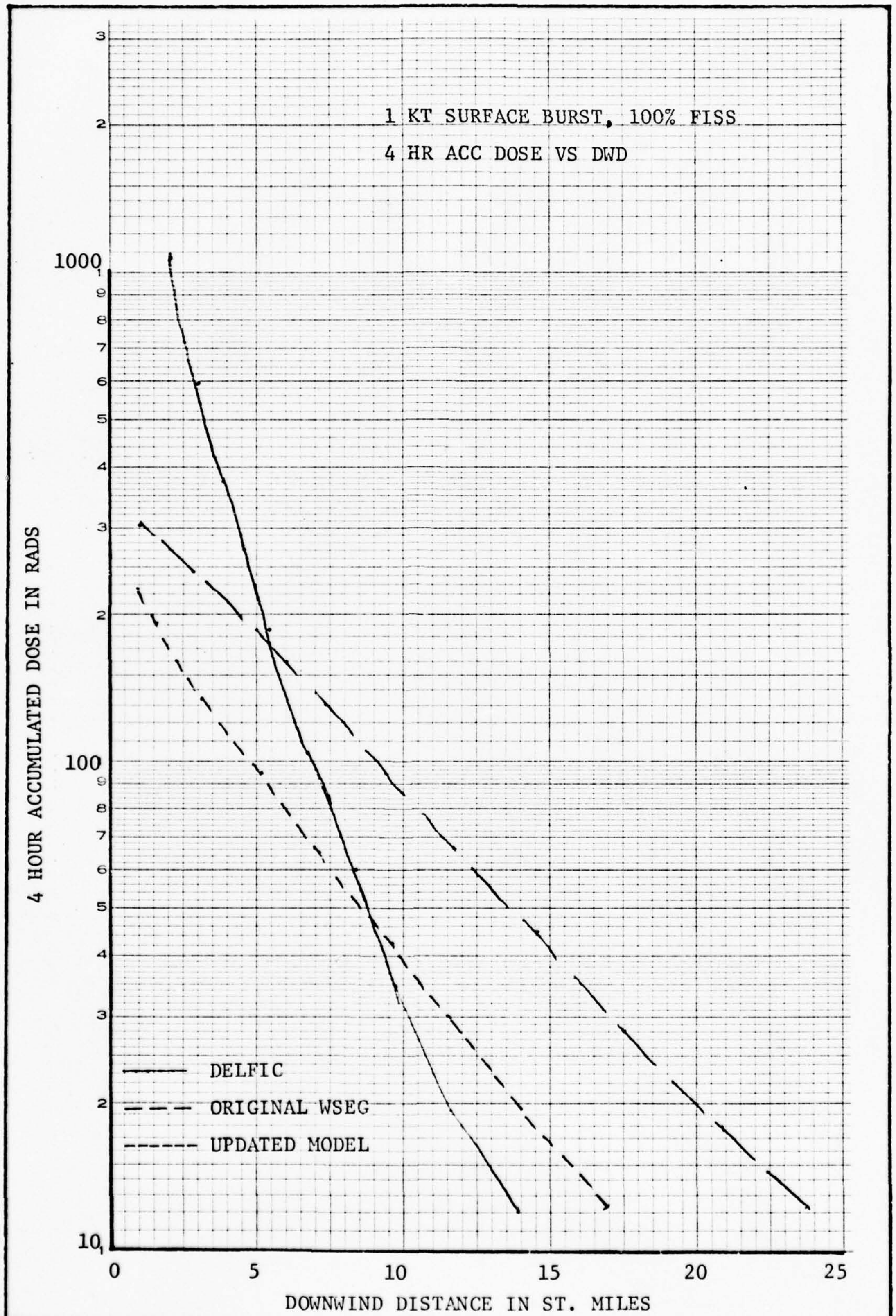
Improved Model Fortran Subroutine FALLY

```
      SUBROUTINE FALLY(YIELD,FISS,HOB,ARRY)
C     TO COMPUTE THE YIELD DEPENDENT PARAMETERS IN THE WSEG 10/-NAS
C     FALLOUT MODEL.   YIELD IS YIELD IN MEGATONS, FISS IS FISSION
C     FRACTION, HOB IS HEIGHT OF BURST IN FEET, ARRY IS AN ARRY OF FORTY
C     ELEMENTS USED TO PRESERVE RESULTS OF DIFFERENT SUBROUTINE CALLS.
C     SUBROUTINES SHOULD BE CALLED IN ORDER OF NEW YIELD, WIND VELOCITY
C     OR WIND SHEAR, DOWNWIND DISTANCE, AND CROSSWIND DISTANCE.
C     THE VALUES IN ARRY(1) TO ARRY(6) ARE FILLED HERE.
      DIMENSION ARRY(1)
      XLNY = ALOG(YIELD)
      TEM=XLNY+5.4
      AK=.9-.4*ALOG10(YIELD)+.3*(ALOG10(YIELD))**2.+.1*(ALOG10(YIELD))
     1**3.
      TEMP=0.70+0.3333333* XLNY-3.25/(4.0+TEM*TEM)
      ARRY (1) = EXP(TEMP)
      ARRY(1)=AK*ARRY(1)
      ARRY(2) = ARRY(1) *ARRY(1)
      TEMP = XLNY +2.42
C   IMPROVED ENW FIT
      ARRY(3)=50.7+20.4*ALOG10(YIELD)+3.5*(ALOG10(YIELD))**2.+2.4*
     1(ALOG10(YIELD))**3.+.6*(ALOG10(YIELD))**4.
C  SIGMA H IS .125 OF H C
    5 ARRY(4)=.125*ARRY(3)
      HCTWO = ARRY(3)/25.
      HCSIX = ARRY(3)/60.
      ARRY(5)=1.0573203*(12.*HCSIX-2.5*HCSIX*HCSIX)*(1.0-0.5*EXP(-HCTWO*
     1HCTWO))
      IF(HOB.GT.0.) GO TO 6
      ARRY(6) = 2000000.*FISS*YIELD
      RETURN
    6 CONTINUE
      XMHB=180.*(YIELD*1000.)**0.4
      IF(HOB.LE.XMHB) GO TO 10
      ARRY(6)=0.
      RETURN
   10 CONTINUE
      TEMP=HOB/XMHB
      AF=0.5*(1.-TEMP)*(1.-TEMP)*(2.+TEMP)+0.001*TEMP
      ARRY(6)=2000000.*FISS*AF*YIELD
      RETURN
      END
```

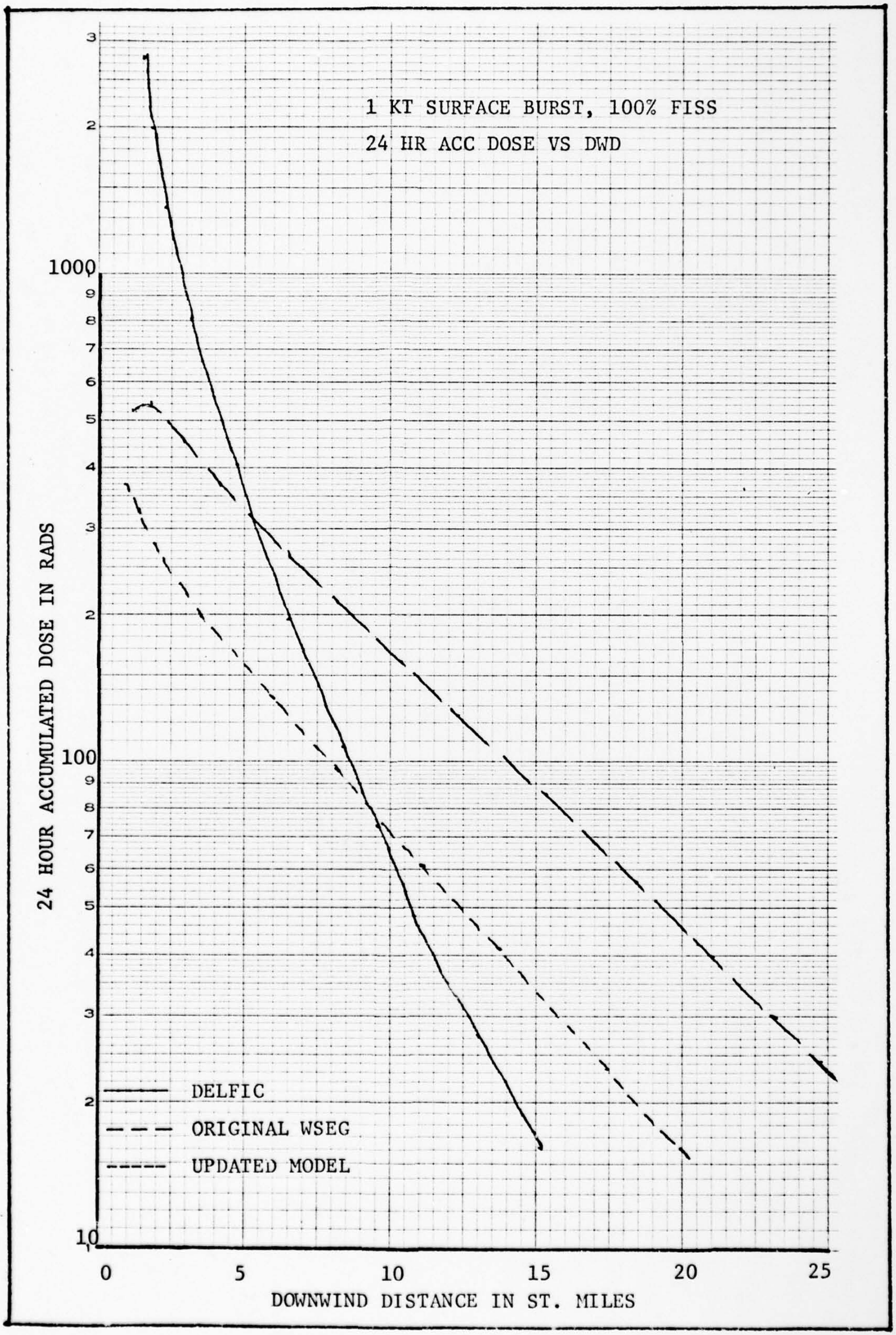
Appendix E

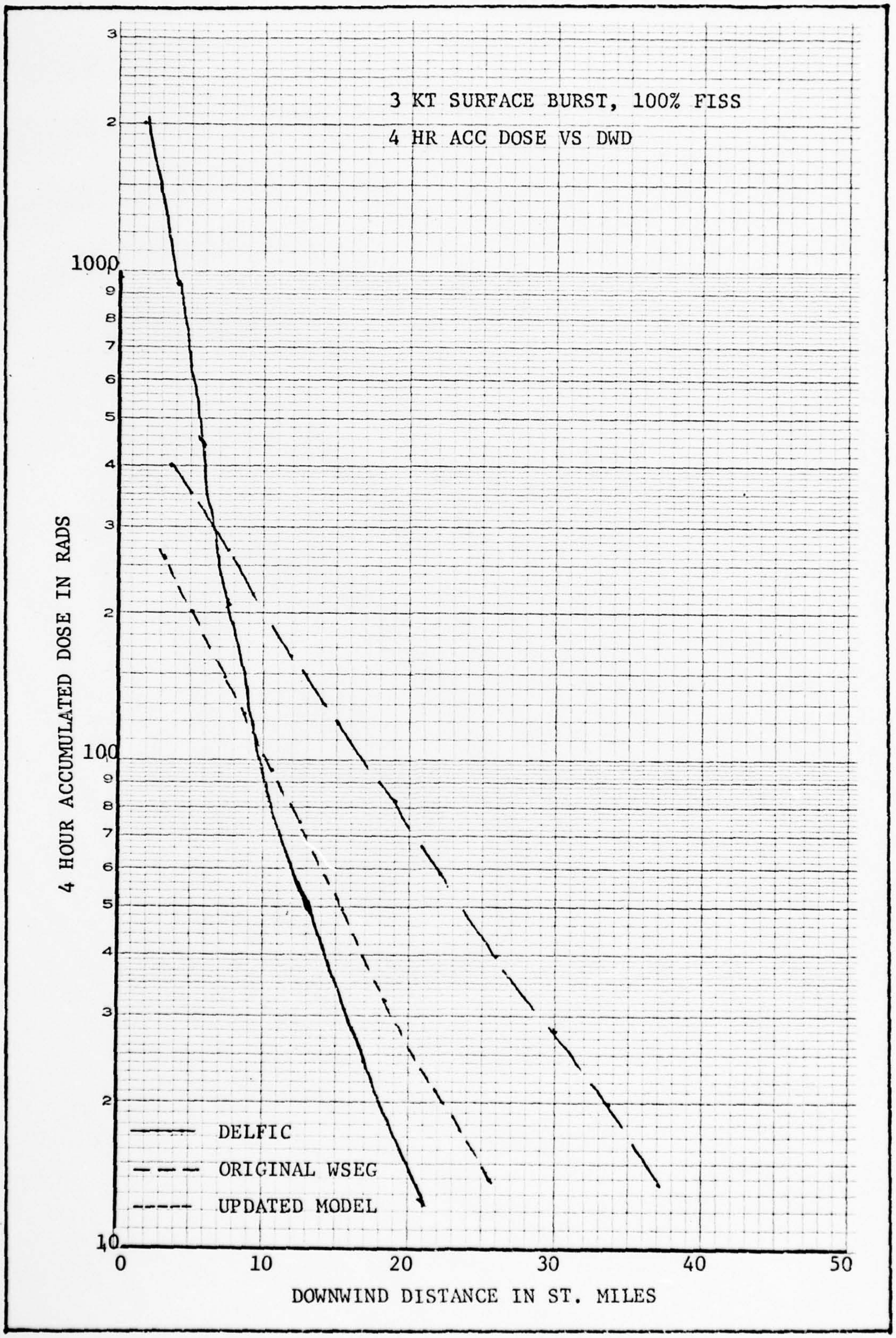
Isodose Contour Length Comparisons

The graphs on the following pages plot accumulated dose in rads versus distance downwind for a number of yields. The original WSEG model, the updated WSEG model, and DELFIC predictions are presented for comparison. Isodose contour lengths are easily compared for the three models by selecting an accumulated dose level on the vertical axis and then reading horizontally to the right until each of the three curves is intercepted. The mileage value on the horizontal axis directly below the intercept point is the maximum length of the contour for that model. All data is for 100% fission yield devices detonated at the surface of the earth. The ground roughness factor is .5.

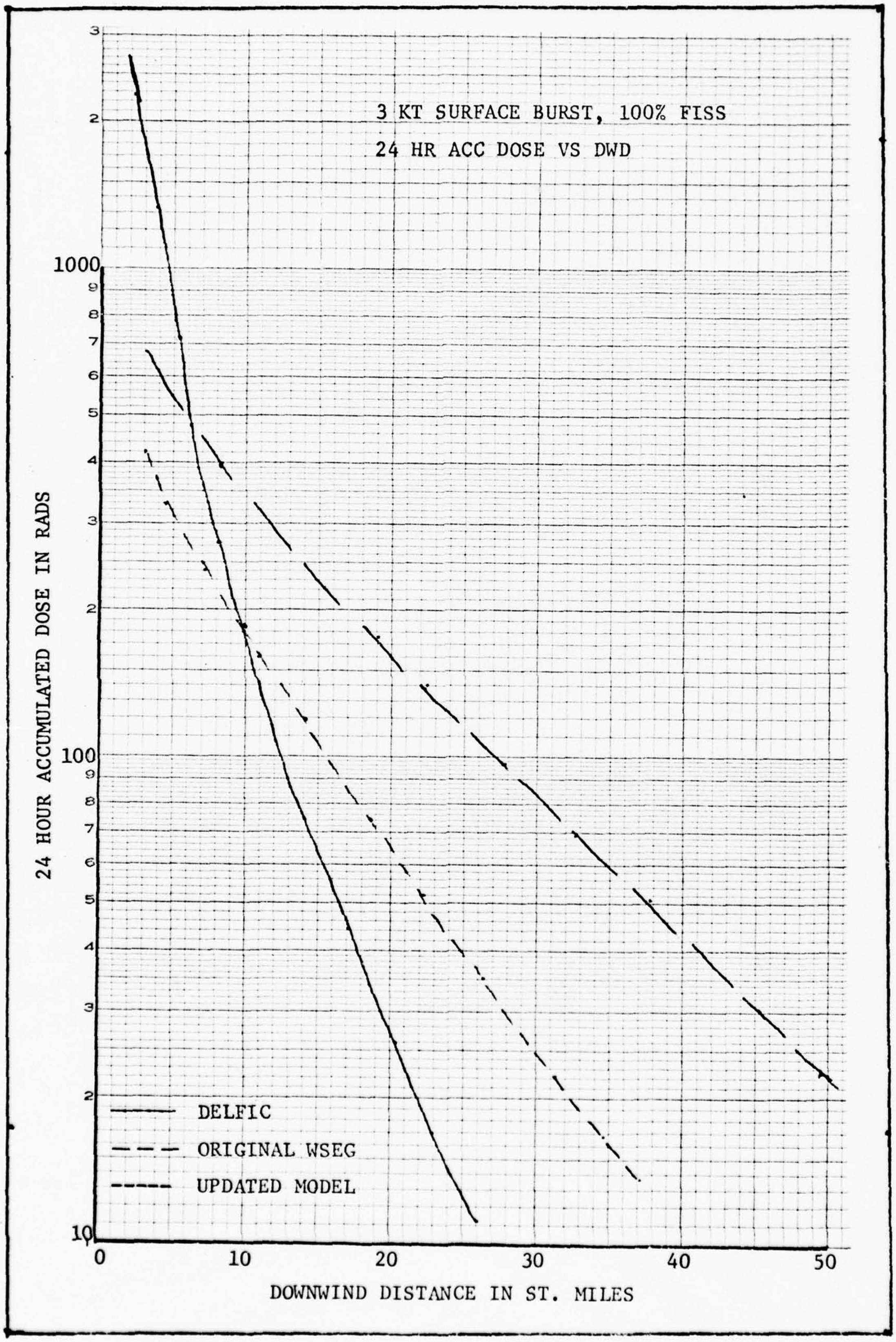


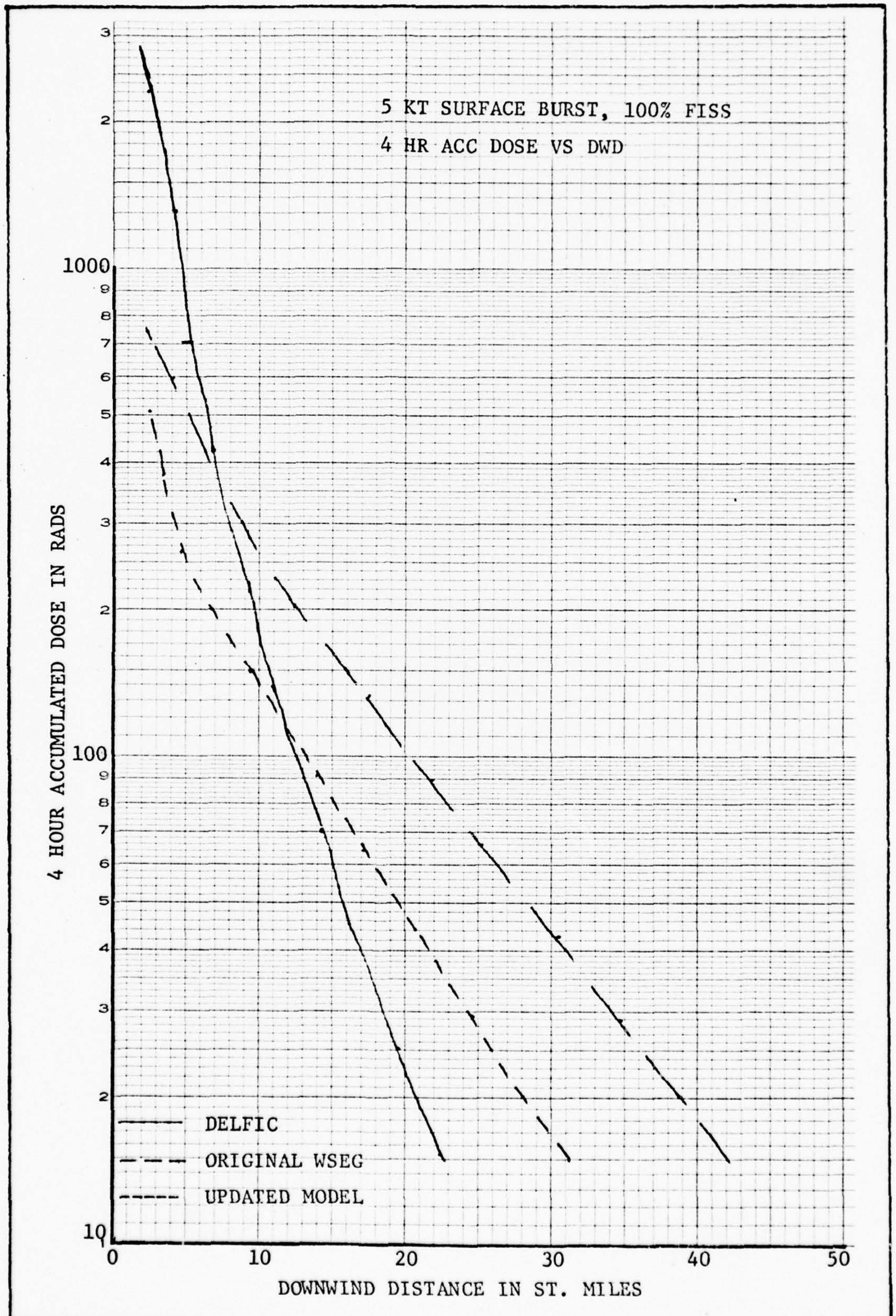
1 KT SURFACE BURST, 100% FISS
4 HR ACC DOSE VS DWD
4 HOUR ACCUMULATED DOSE IN RADS
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL WSEG
UPDATED MODEL
1000
100
10
0
5
10
15
20
25

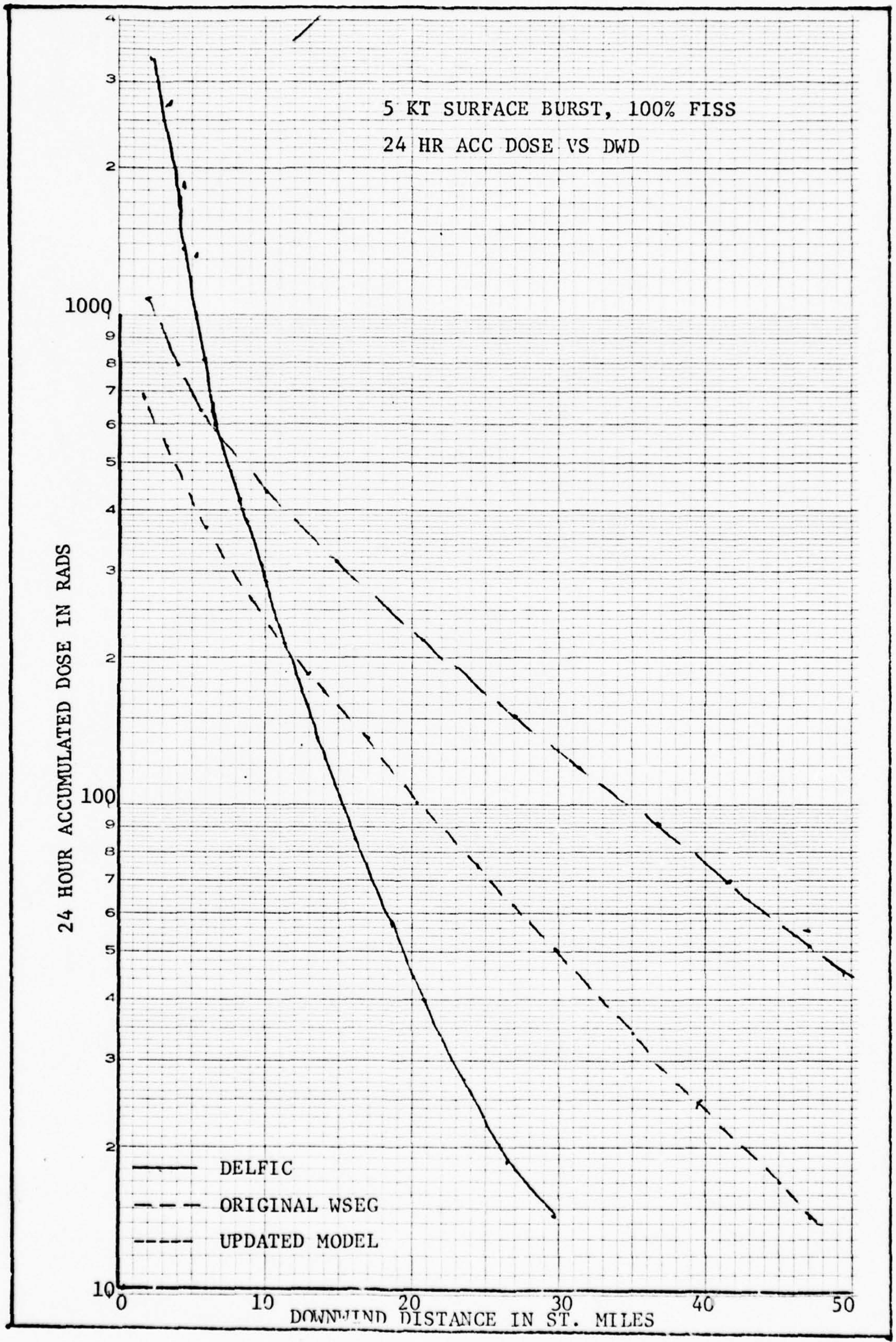

1 KT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
24 HOUR ACCUMULATED DOSE IN RADS
DOWNWIND DISTANCE IN ST. MILES
1000
100
10
0
5
10
15
20
25
DELFIC
ORIGINAL WSEG
UPDATED MODEL

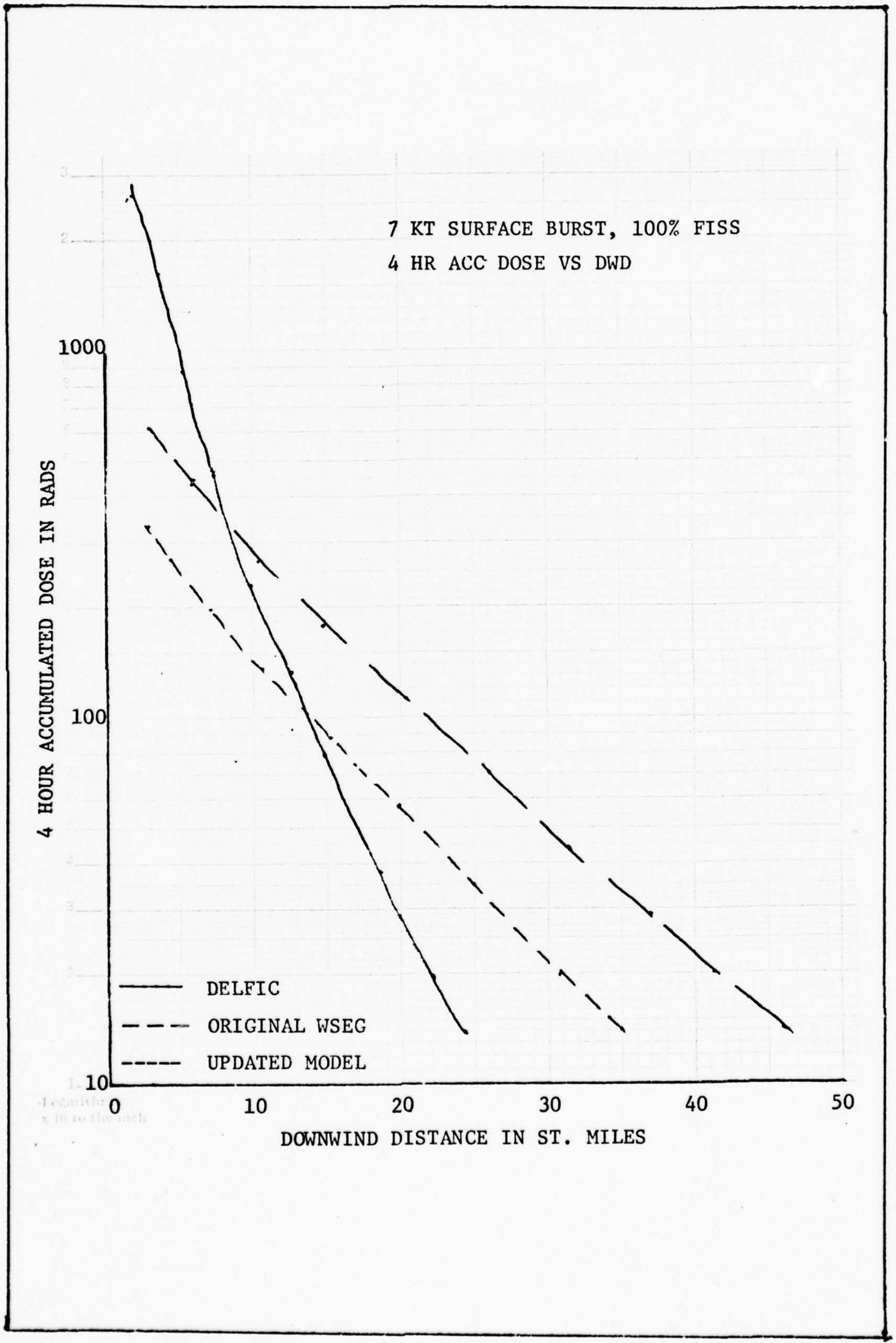


3 KT SURFACE BURST, 100% FISS
4 HR ACC DOSE VS DWD
4 HOUR ACCUMULATED DOSE IN RADS
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL WSEG
UPDATED MODEL
10
100
1000
0
10
20
30
40
50

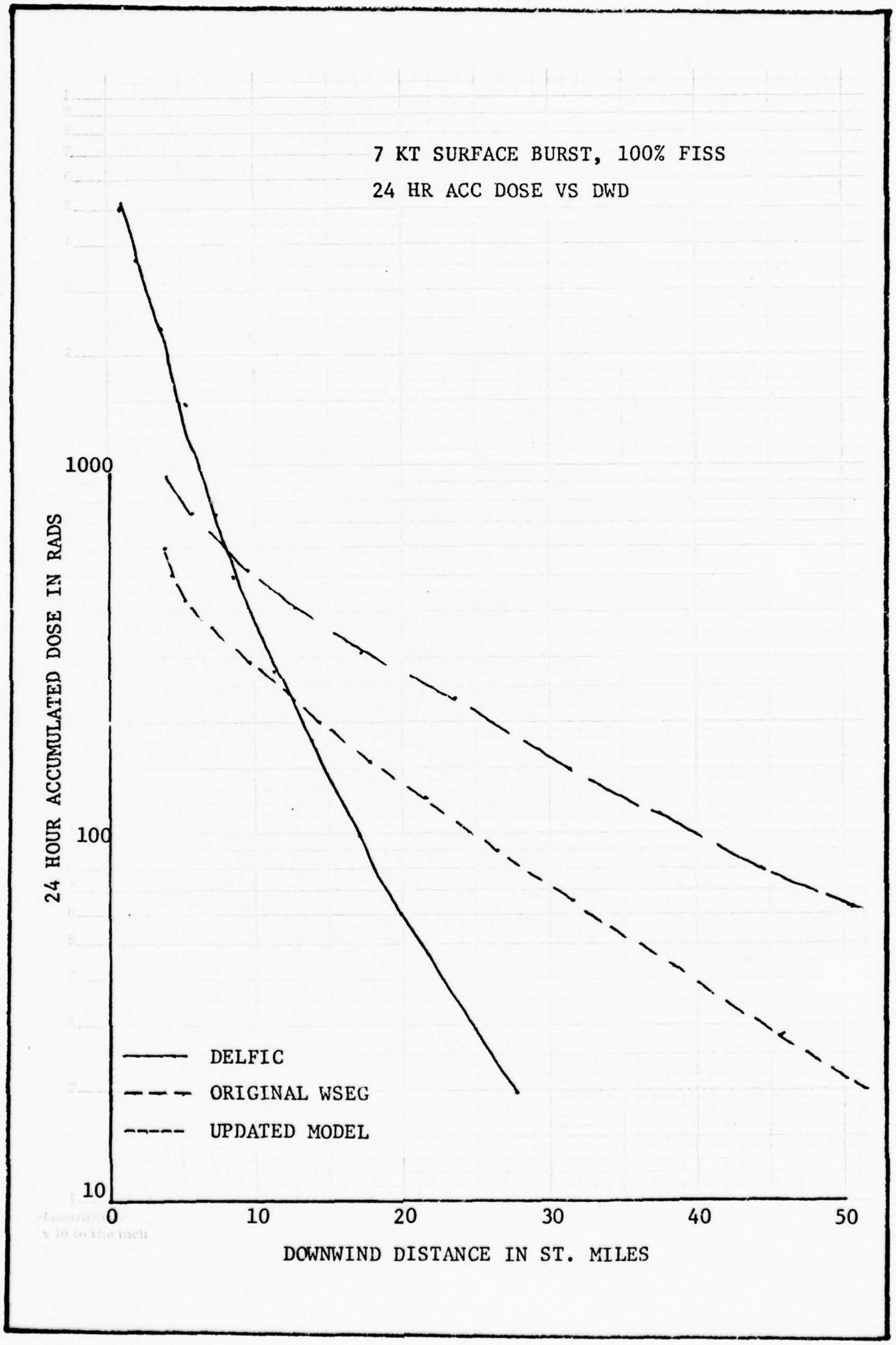

3 KT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
24 HOUR ACCUMULATED DOSE IN RADS
3
2
1000
9
8
7
6
5
4
3
2
100
9
8
7
6
5
4
3
2
10
0
10
20
30
40
50
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL WSEG
UPDATED MODEL


5 KT SURFACE BURST, 100% FISS
4 HR ACC DOSE VS DWD
4 HOUR ACCUMULATED DOSE IN RADS
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL WSEG
UPDATED MODEL
10
100
1000
0
10
20
30
40
50

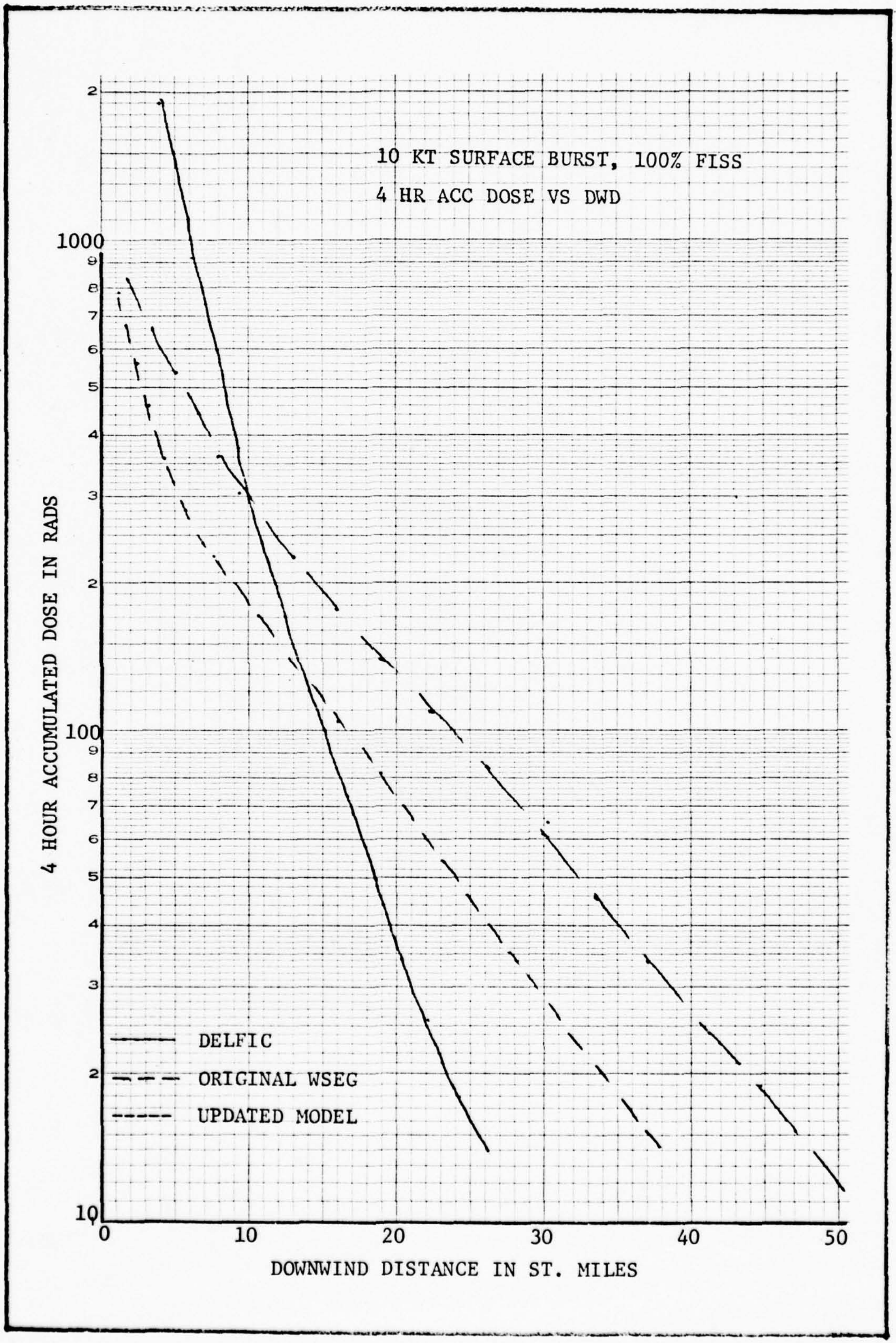

5 KT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
24 HOUR ACCUMULATED DOSE IN RADS
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL WSEG
UPDATED MODEL
1000
100
10
0
10
20
30
40
50



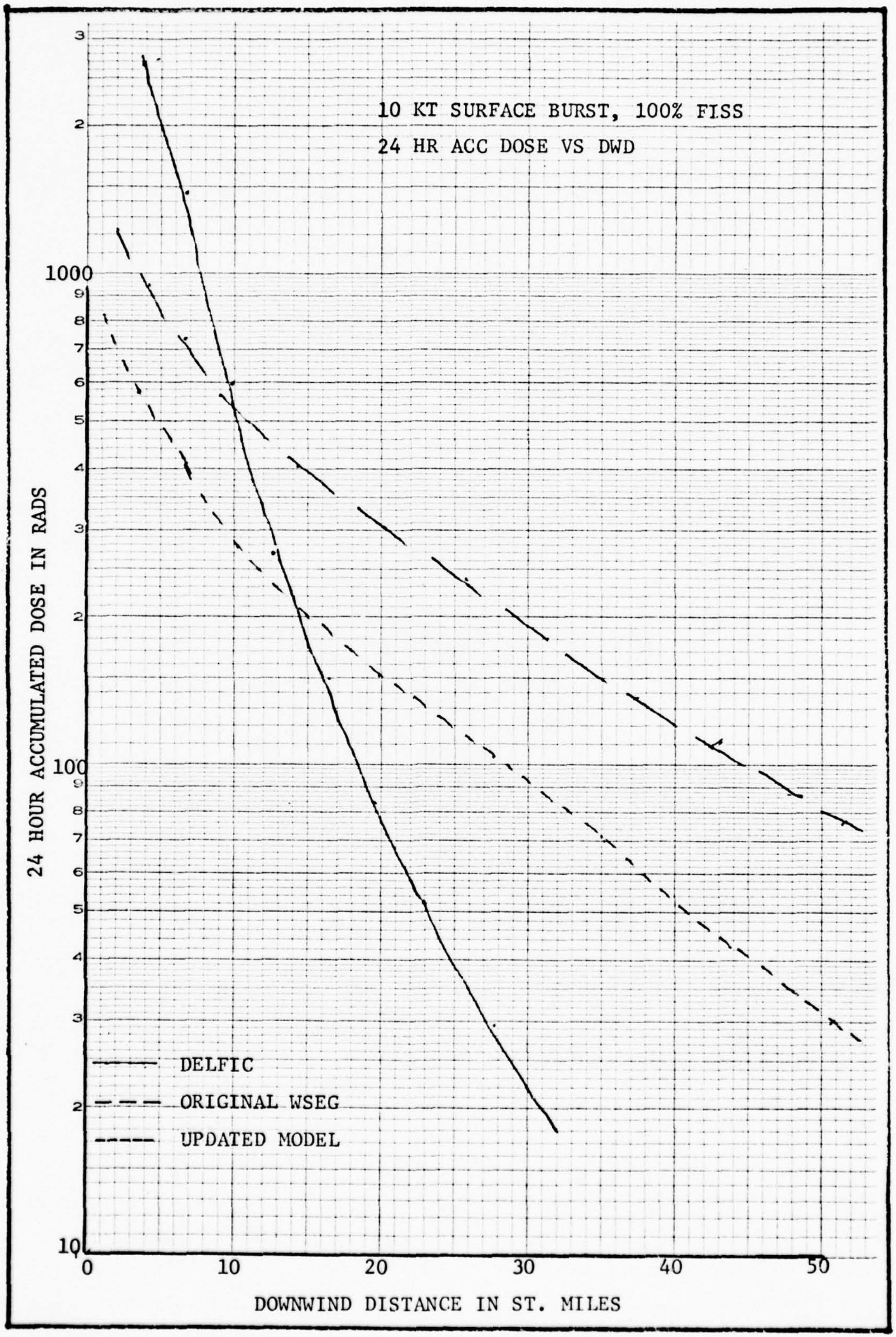
7 KT SURFACE BURST, 100% FISS
4 HR ACC DOSE VS DWD
4 HOUR ACCUMULATED DOSE IN RADS
1000
100
10
0
10
20
30
40
50
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL WSEG
UPDATED MODEL

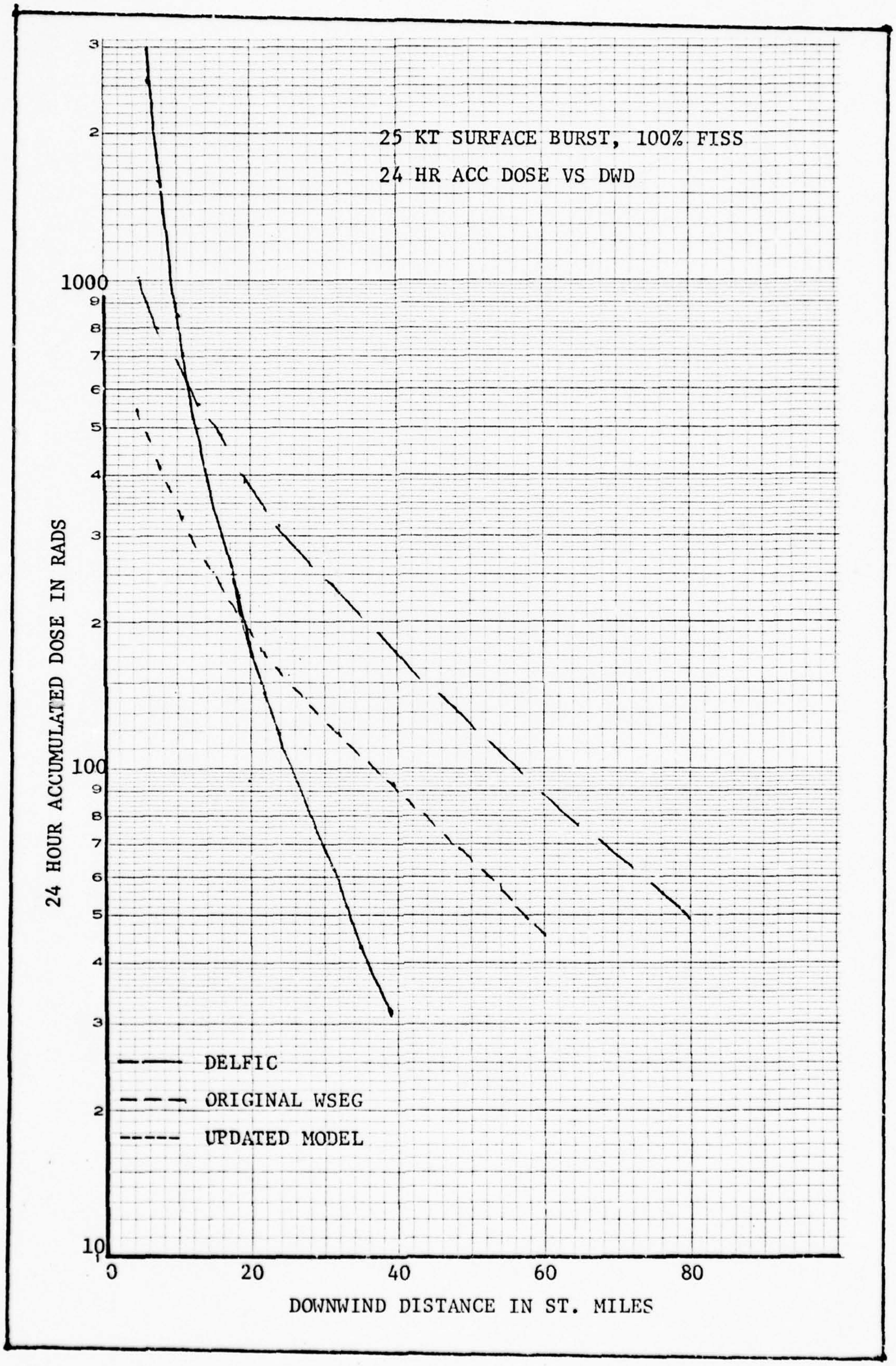


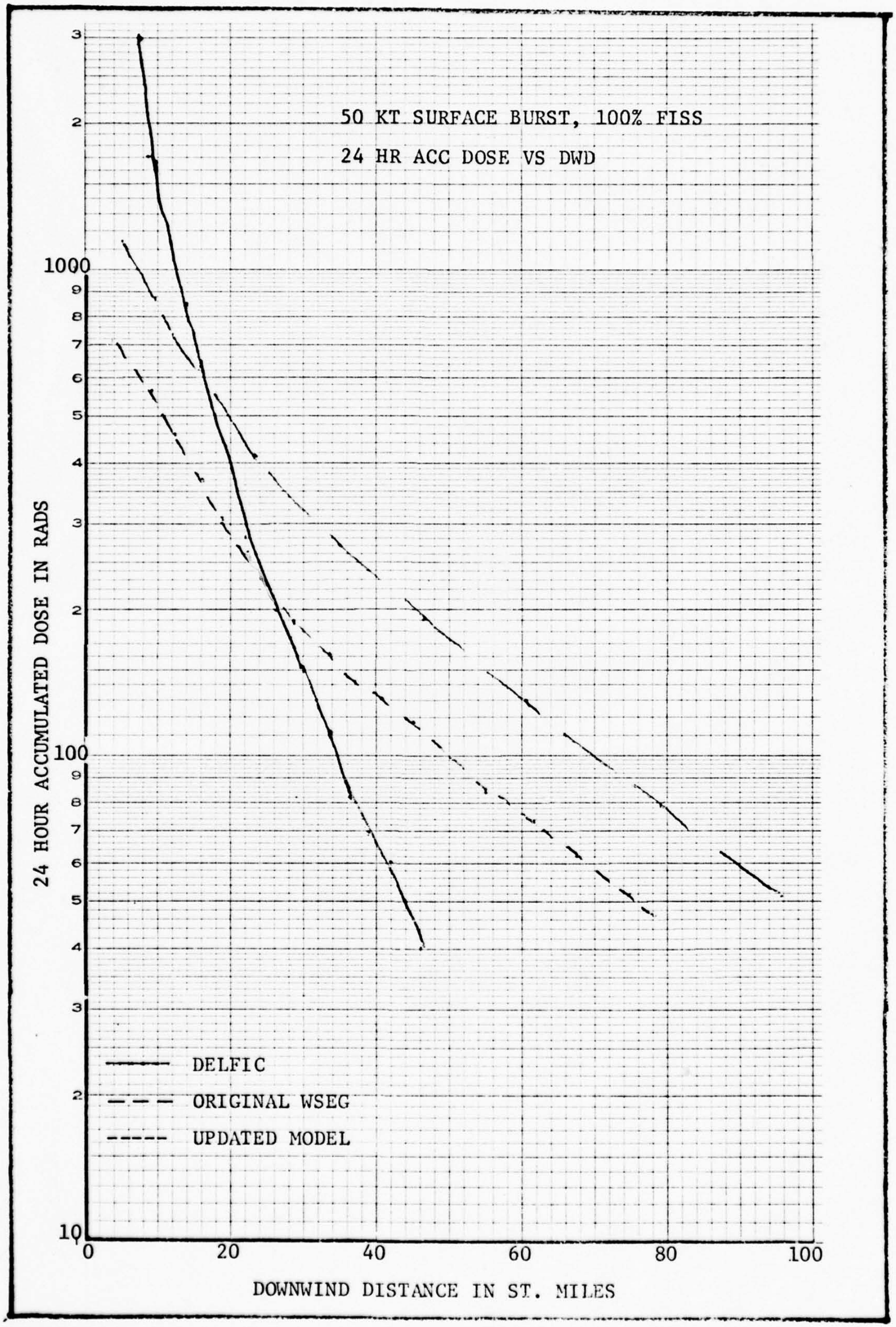
7 KT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
24 HOUR ACCUMULATED DOSE IN RADS
1000
100
10
0
10
20
30
40
50
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL WSEG
UPDATED MODEL

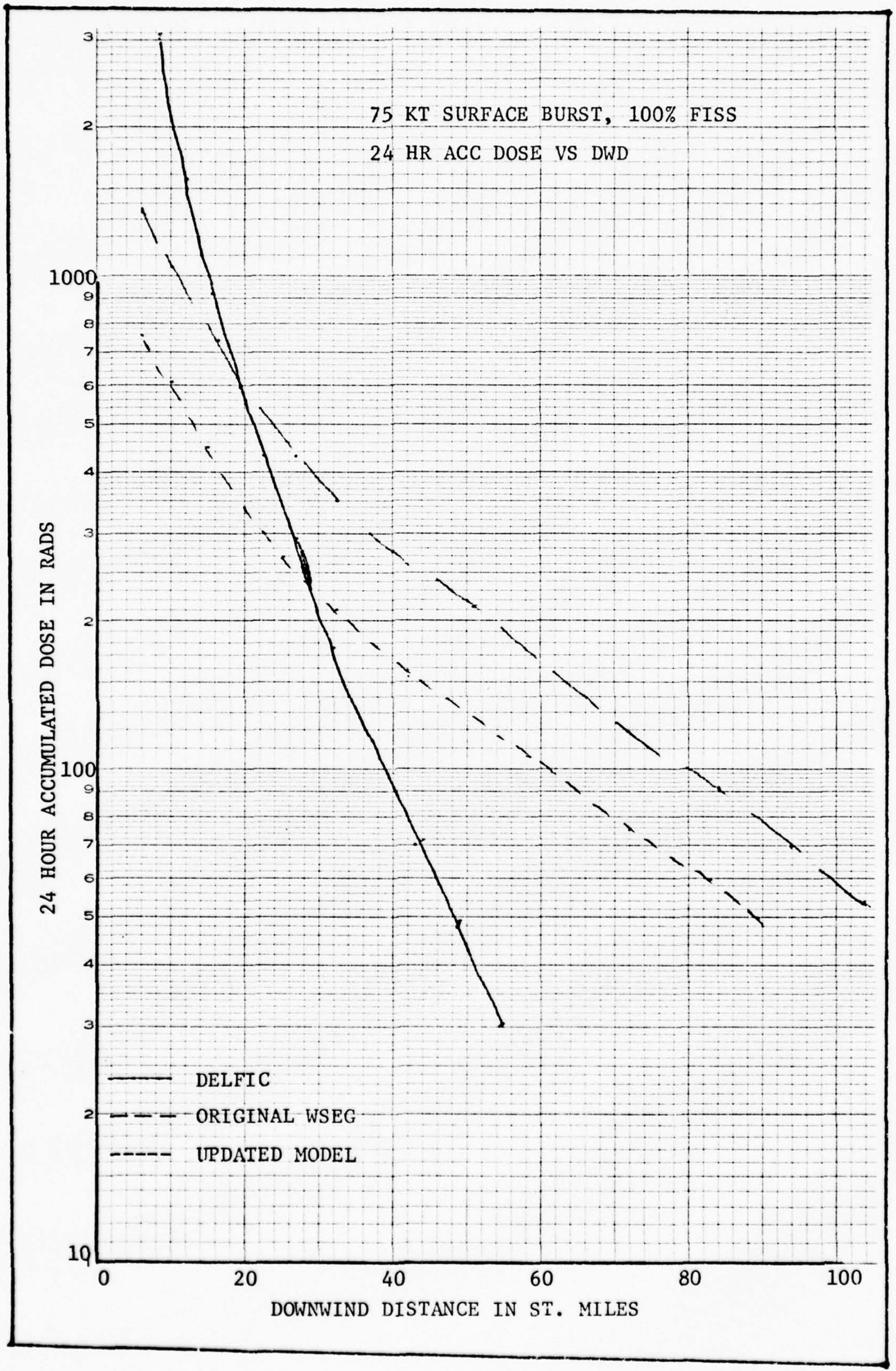


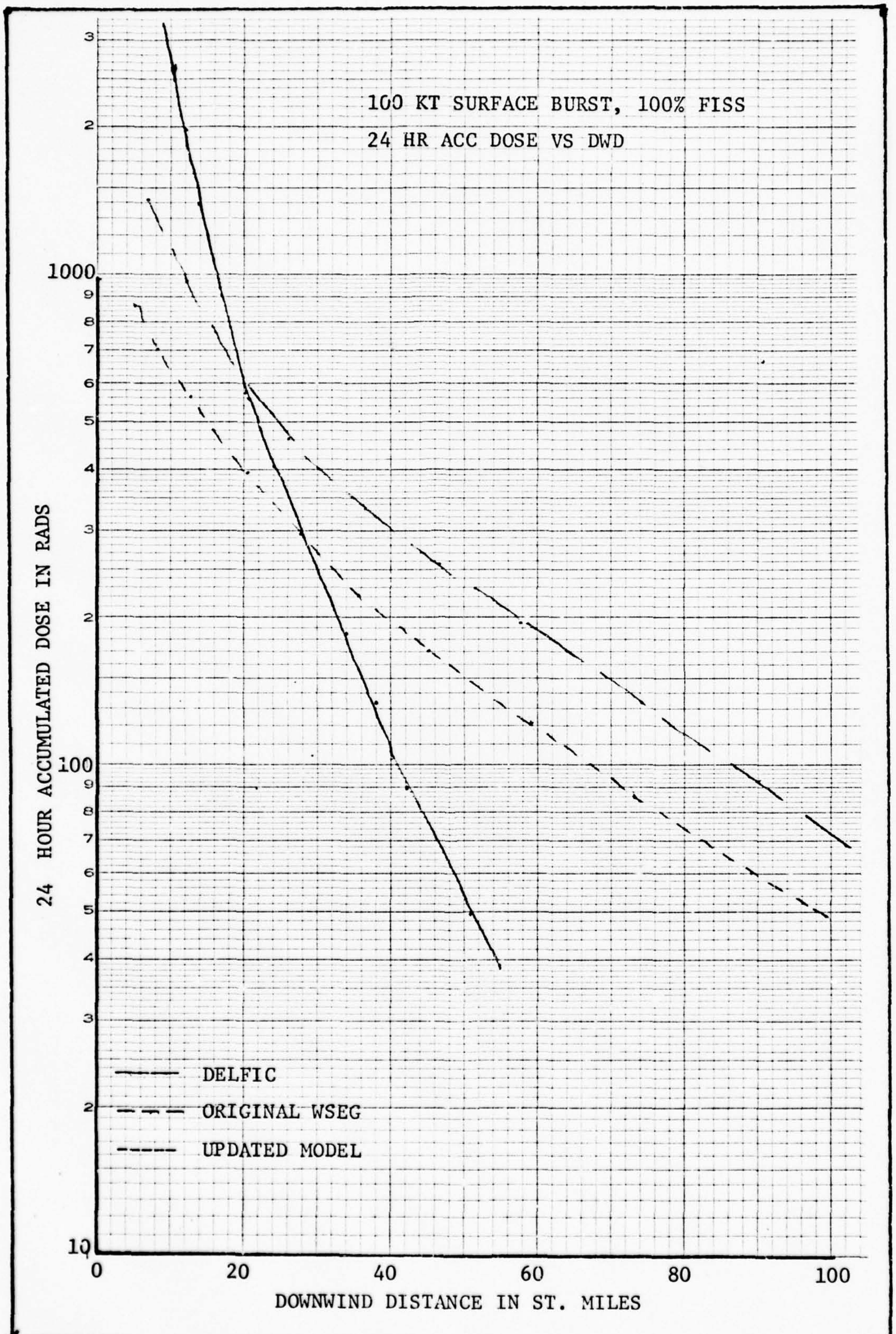
10 KT SURFACE BURST, 100% FISS
4 HR ACC DOSE VS DWD
4 HOUR ACCUMULATED DOSE IN RADS
2
1000
9
8
7
6
5
4
3
2
100
9
8
7
6
5
4
3
2
10
0
10
20
30
40
50
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL WSEG
UPDATED MODEL

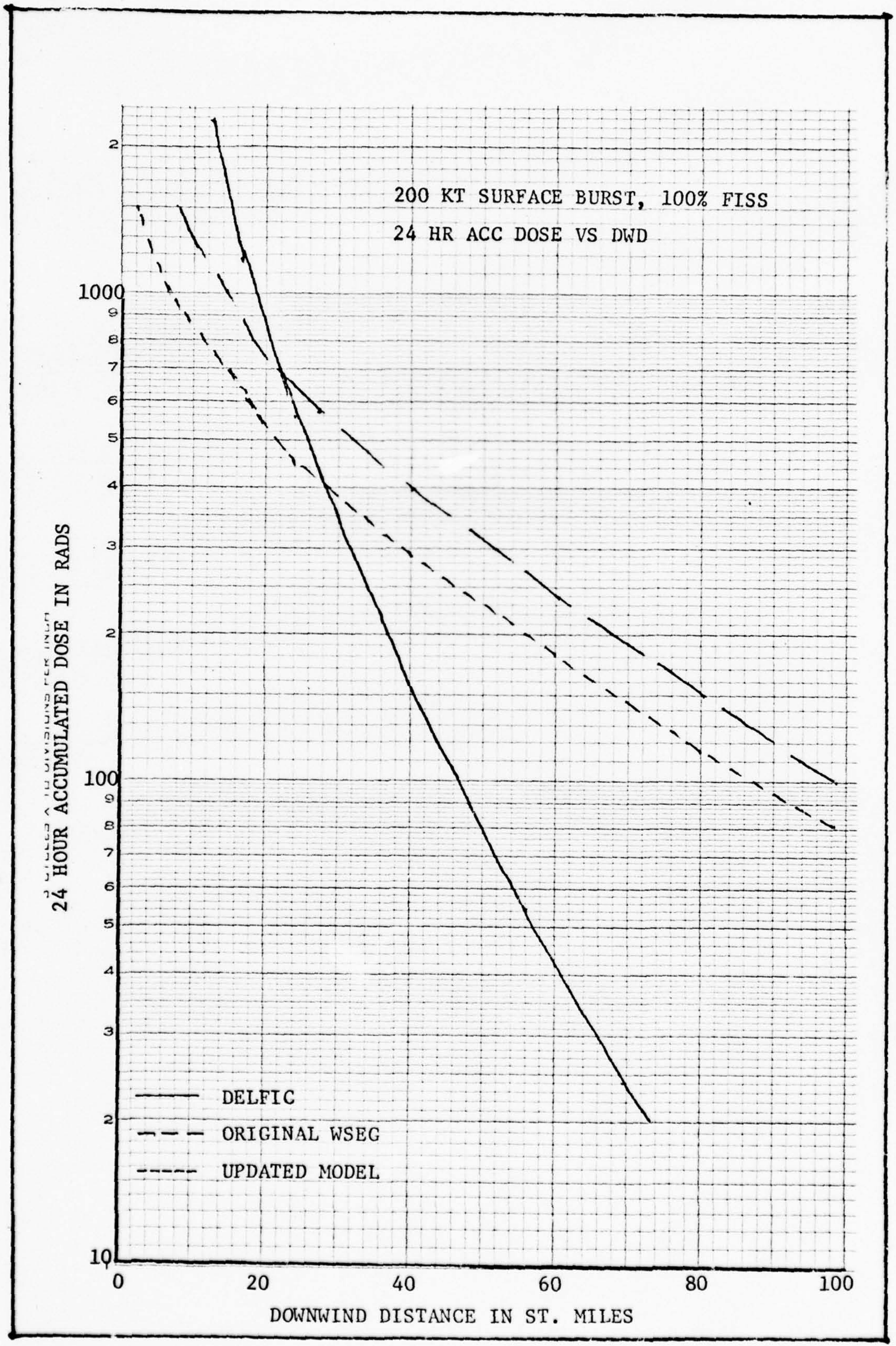

10 KT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
24 HOUR ACCUMULATED DOSE IN RADS
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL WSEG
UPDATED MODEL
10
100
1000
0
10
20
30
40
50


25 KT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
24 HOUR ACCUMULATED DOSE IN RADS
DOWNWIND DISTANCE IN ST. MILES
1000
100
10
0
20
40
60
80
DELFIC
ORIGINAL WSEG
UPDATED MODEL

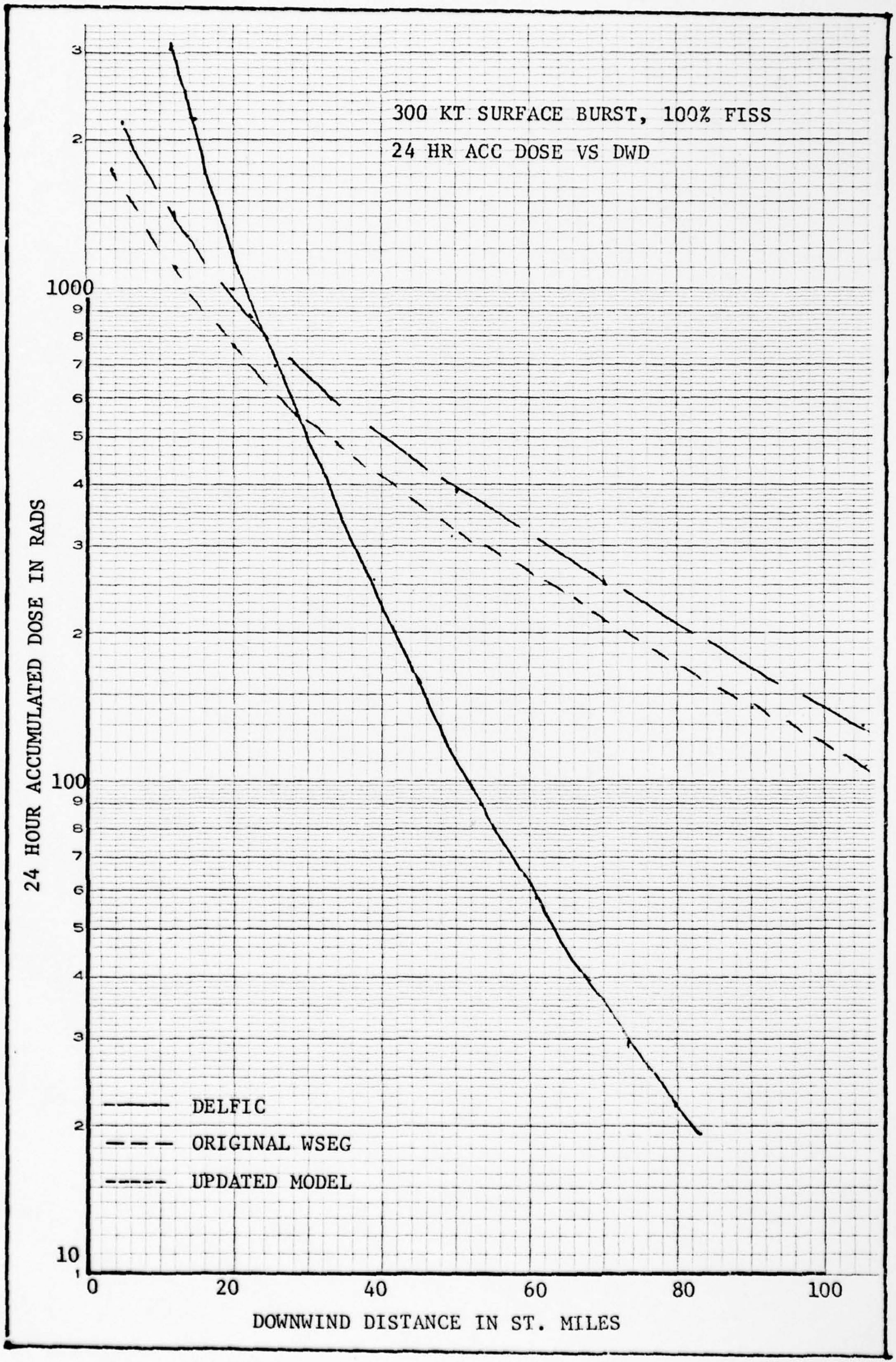

50 KT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
24 HOUR ACCUMULATED DOSE IN RADS
DOWNWIND DISTANCE IN ST. MILES
10
100
1000
0
20
40
60
80
100
DELFIC
ORIGINAL WSEG
UPDATED MODEL


75 KT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
24 HOUR ACCUMULATED DOSE IN RADS
DOWNWIND DISTANCE IN ST. MILES
0
20
40
60
80
100
10
100
1000
DELFIC
ORIGINAL WSEG
UPDATED MODEL

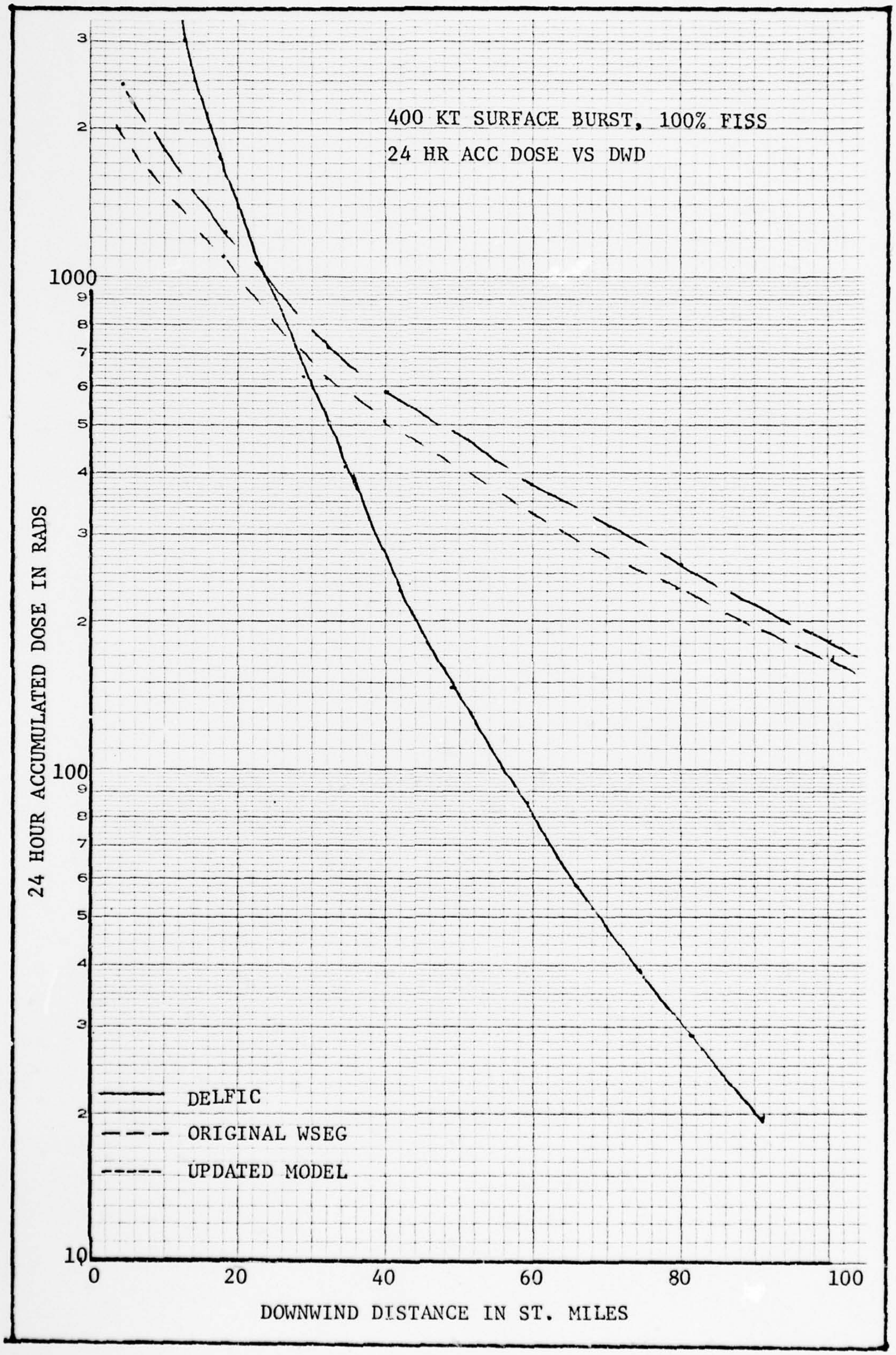

100 KT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
24 HOUR ACCUMULATED DOSE IN RADS
DOWNWIND DISTANCE IN ST. MILES
1000
100
10
0
20
40
60
80
100
DELFIC
ORIGINAL WSEG
UPDATED MODEL

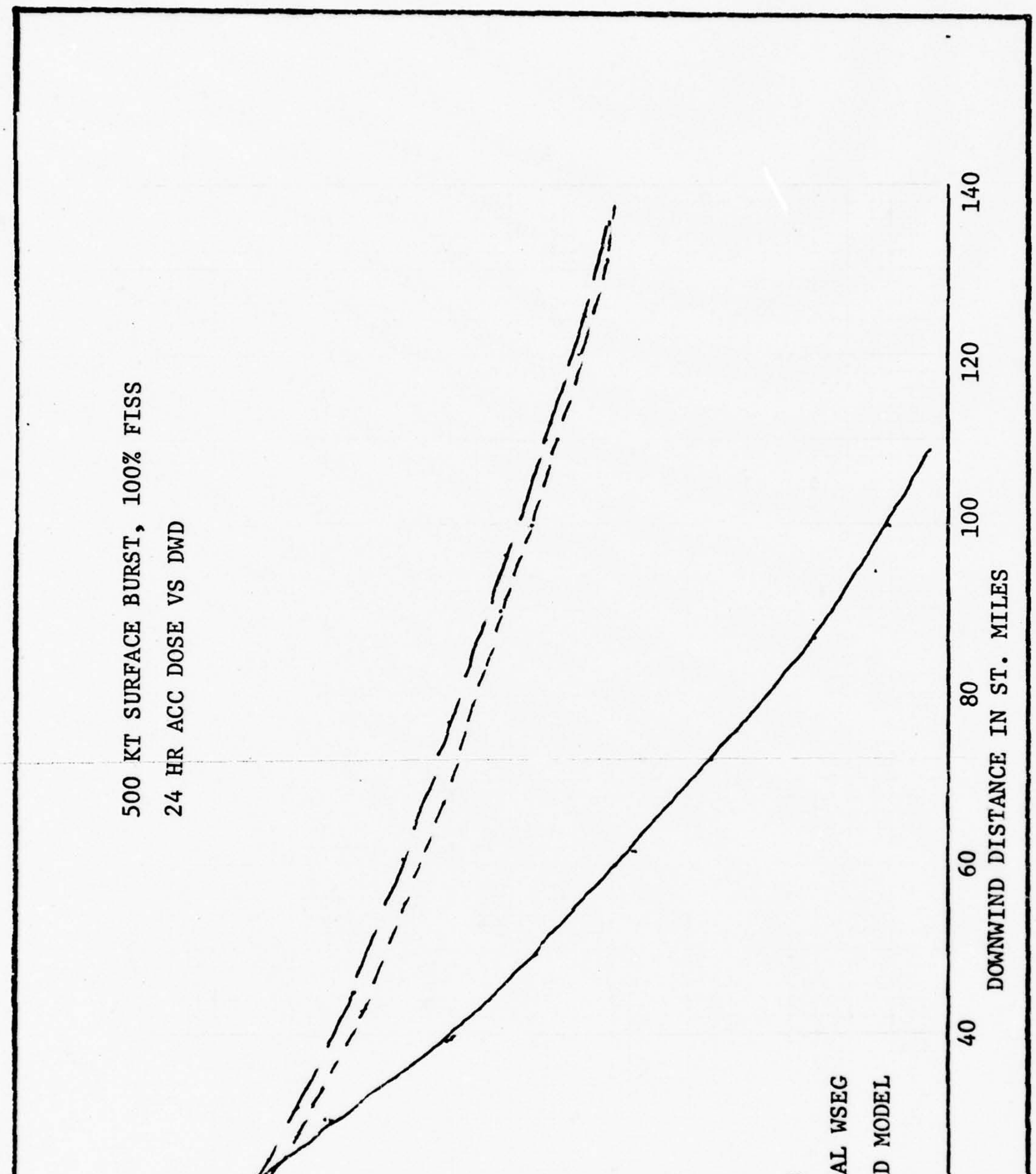


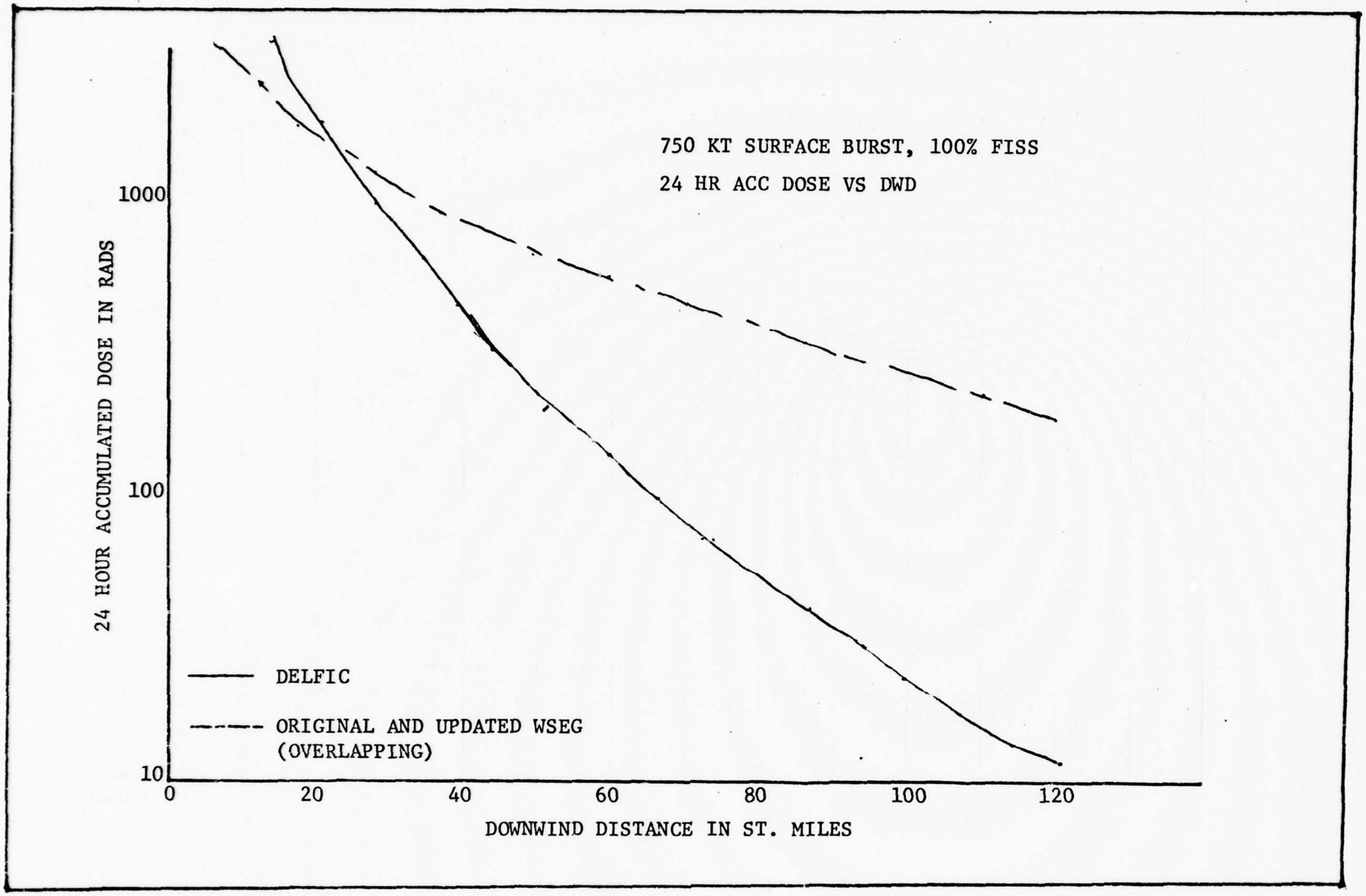
200 KT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
24 HOUR ACCUMULATED DOSE IN RADS
DOWNWIND DISTANCE IN ST. MILES
0
20
40
60
80
100
10
100
1000
DELFIC
ORIGINAL WSEG
UPDATED MODEL

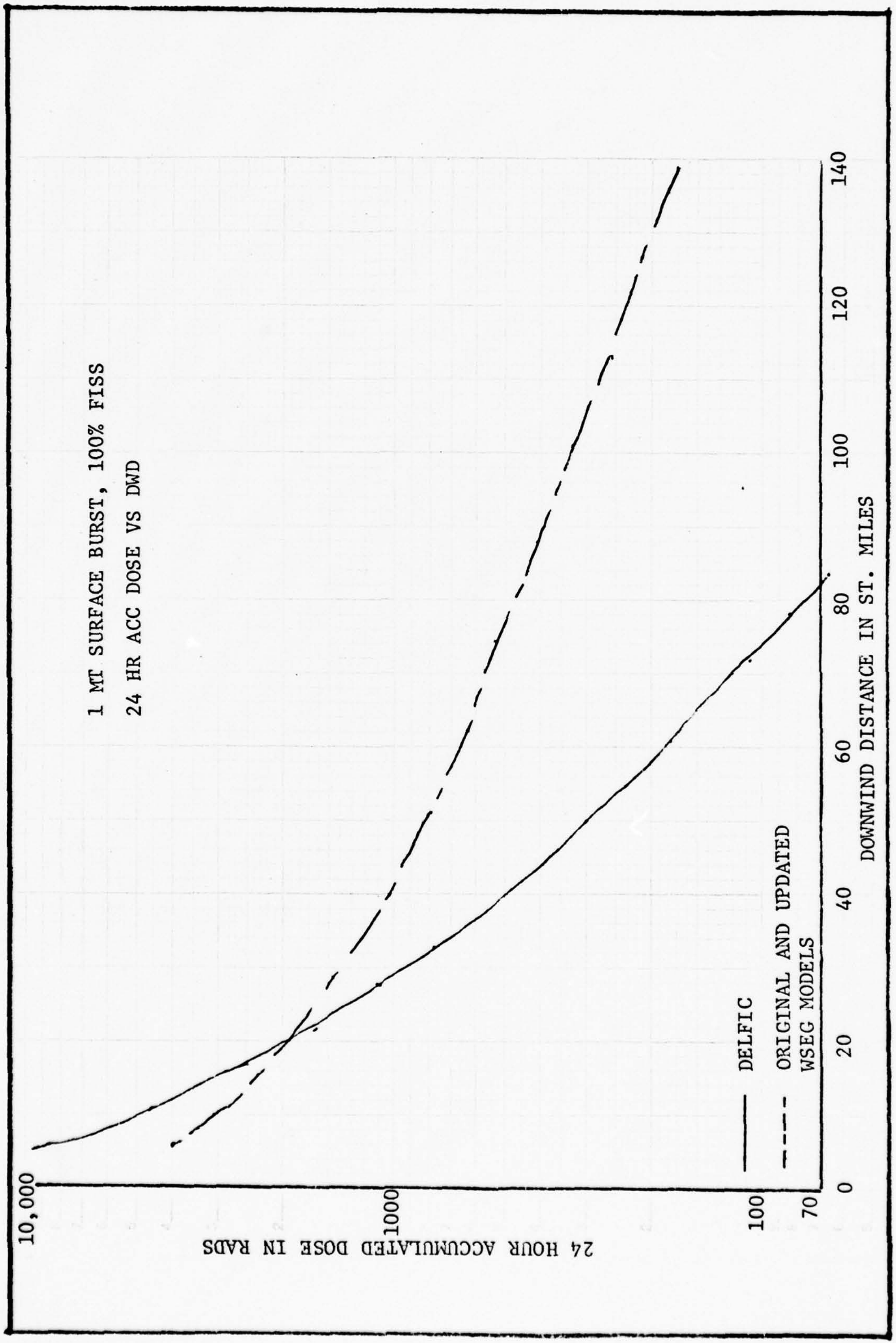


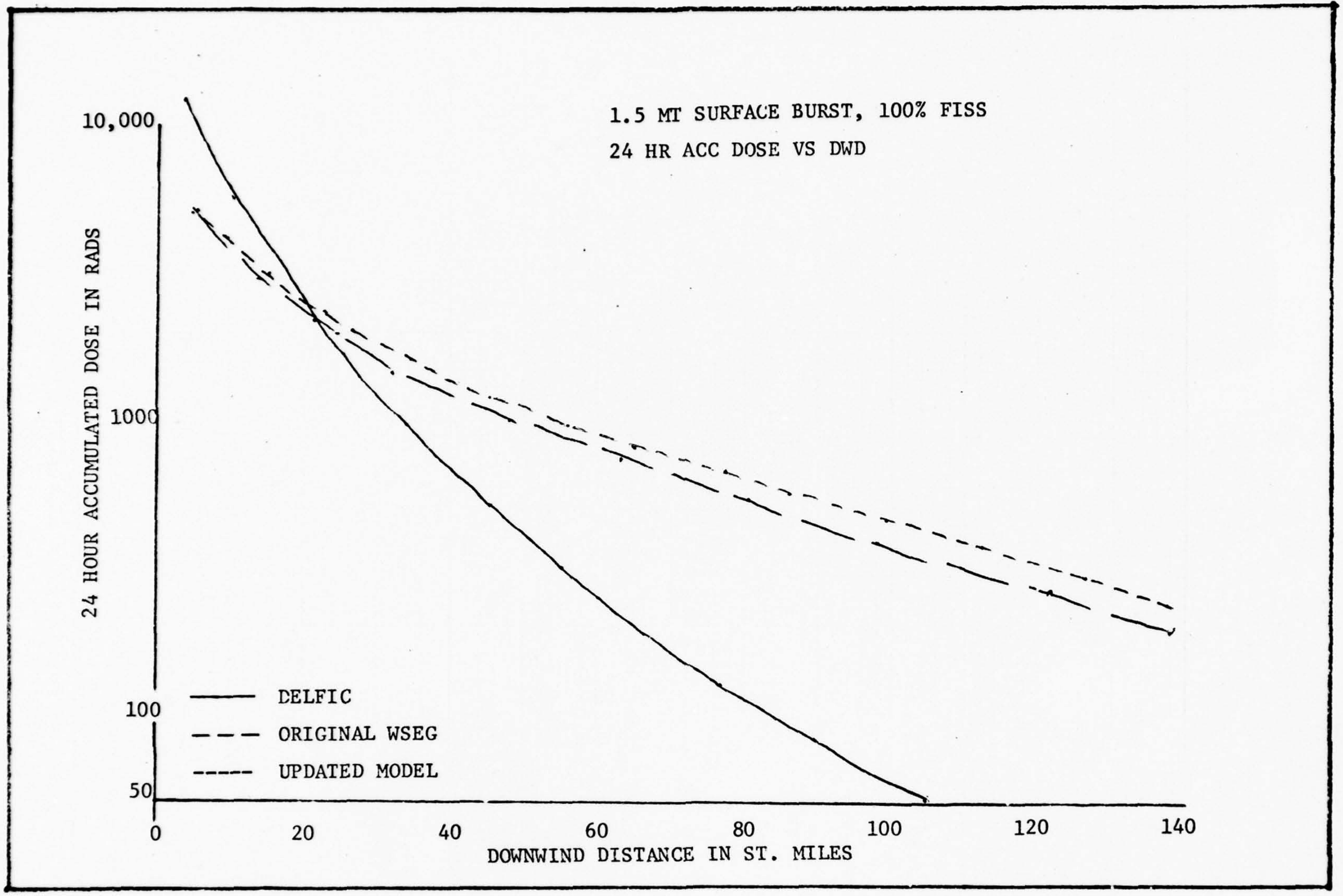
300 KT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
24 HOUR ACCUMULATED DOSE IN RADS
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL WSEG
UPDATED MODEL
0
20
40
60
80
100
10
100
1000

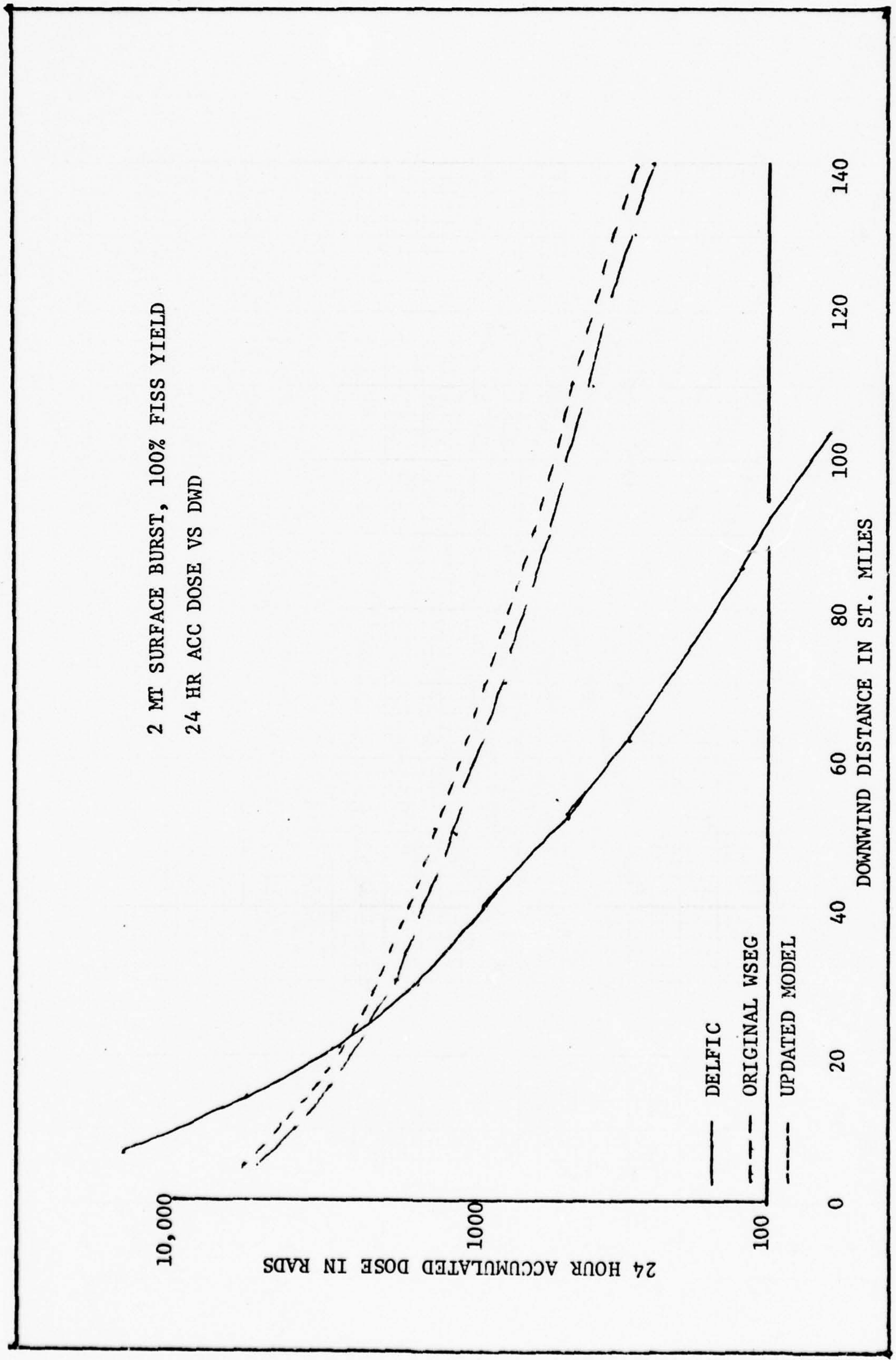

400 KT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
24 HOUR ACCUMULATED DOSE IN RADS
1000
100
10
0
20
40
60
80
100
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL WSEG
UPDATED MODEL

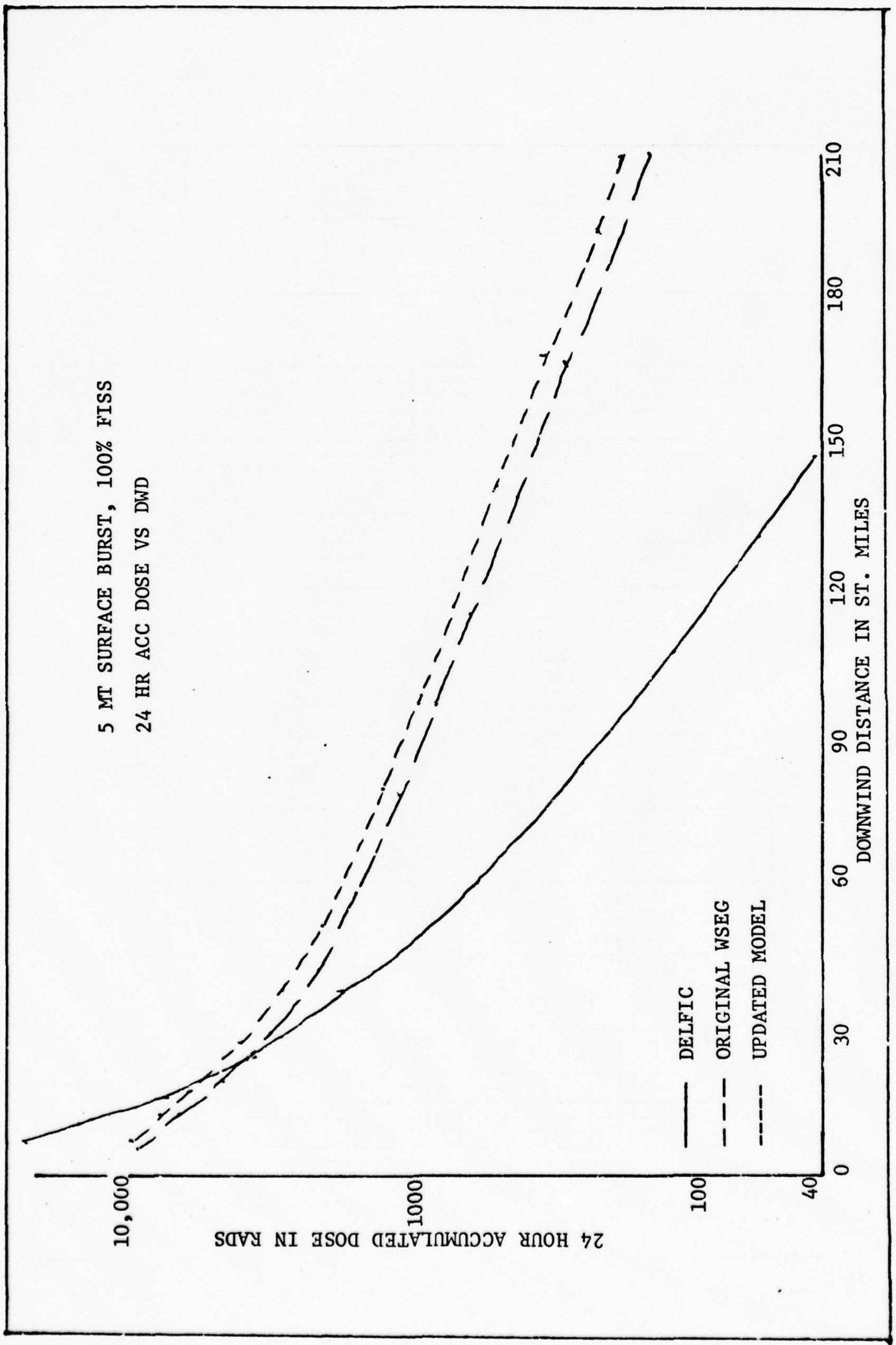

500 KT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
DELFIC
ORIGINAL WSEG
UPDATED MODEL
24 HOUR ACCUMULATED DOSE IN RADS
1000
100
10
DOWNWIND DISTANCE IN ST. MILES
0
20
40
60
80
100
120
140


750 KT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
24 HOUR ACCUMULATED DOSE IN RADS
1000
100
10
0
20
40
60
80
100
120
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL AND UPDATED WSEG
(OVERLAPPING)

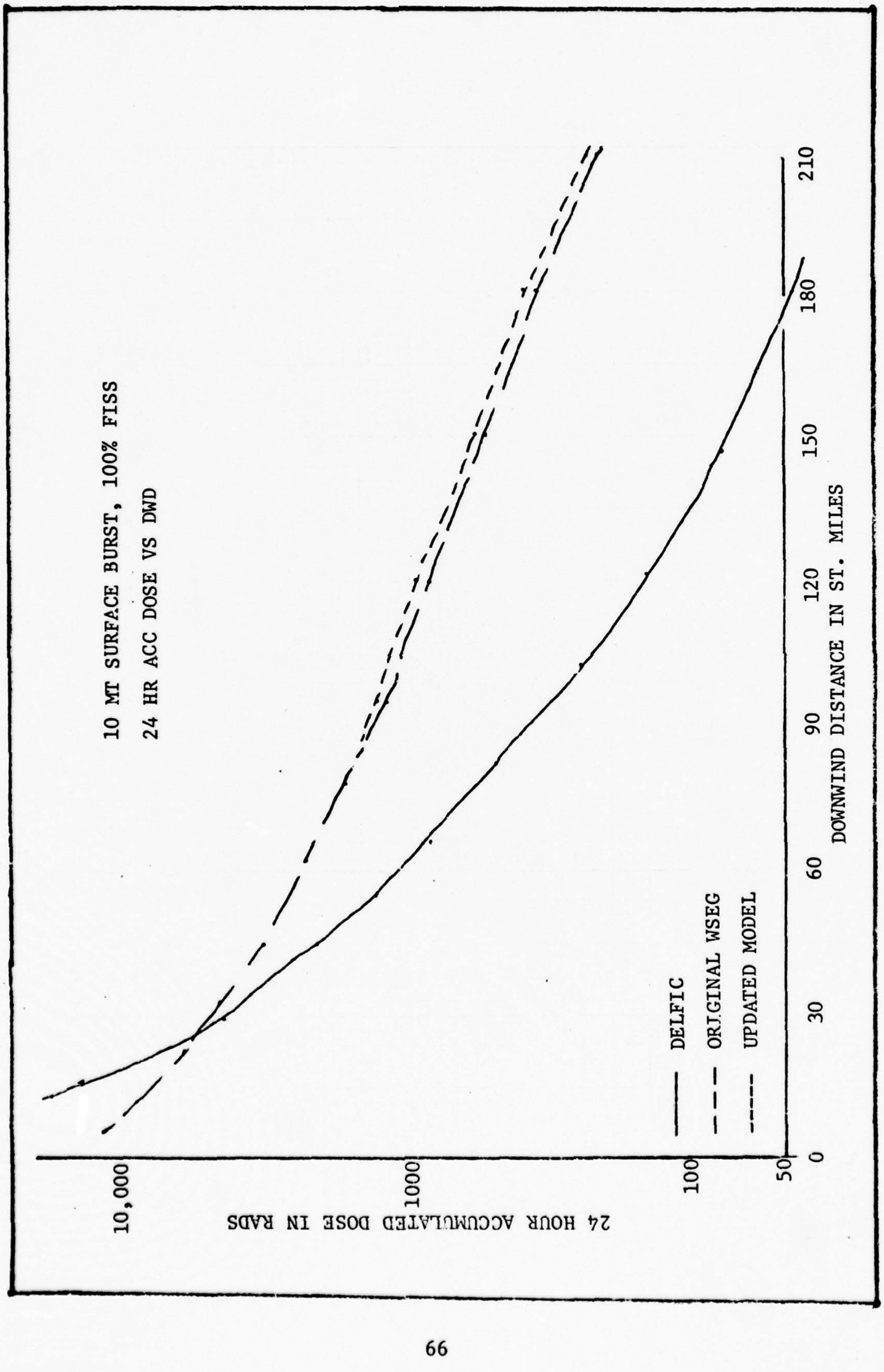

1 MT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
DELFIC
ORIGINAL AND UPDATED WSEG MODELS
24 HOUR ACCUMULATED DOSE IN RADS
10,000
1000
100
70
DOWNWIND DISTANCE IN ST. MILES
0
20
40
60
80
100
120
140

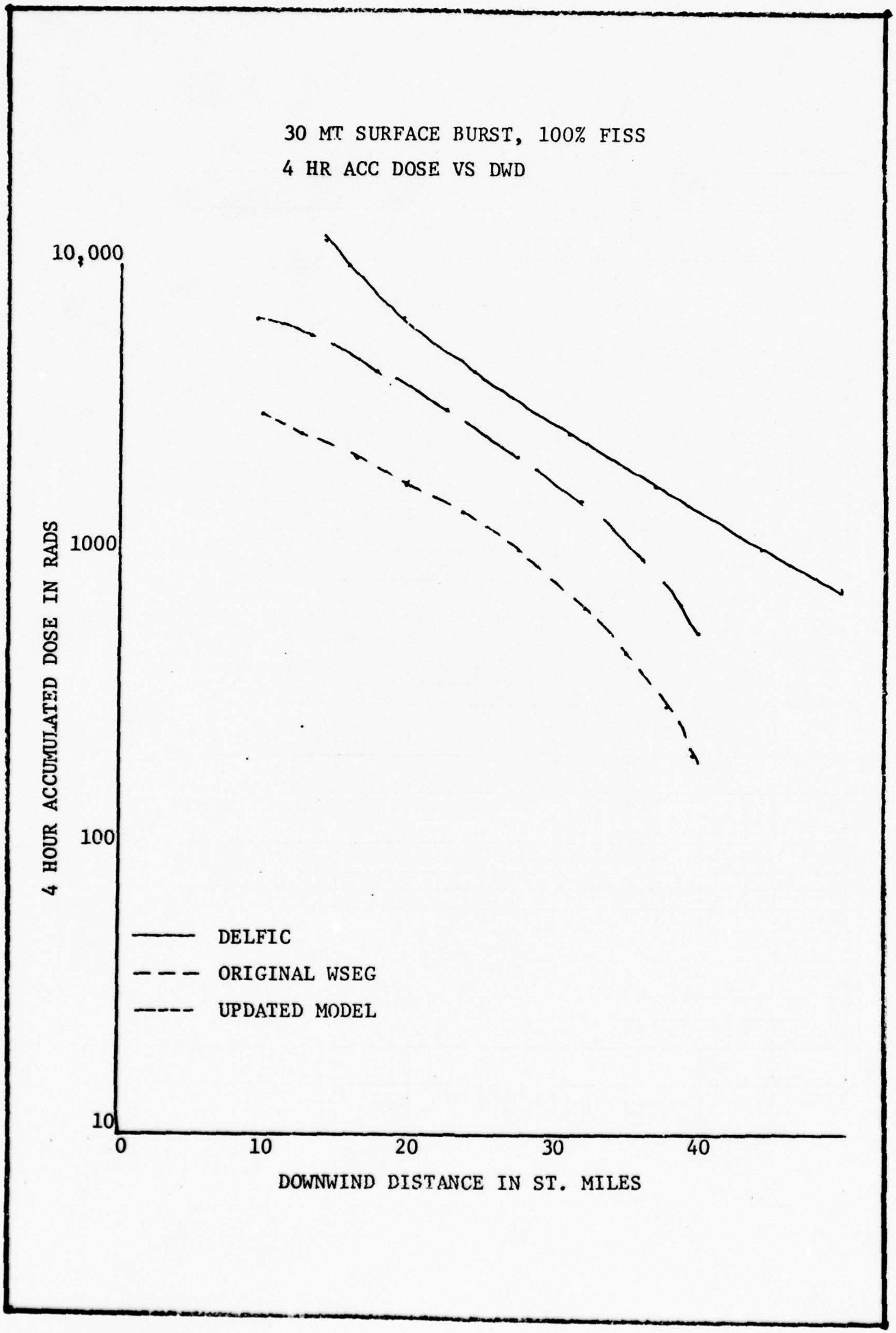

1.5 MT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
10,000
1000
100
50
24 HOUR ACCUMULATED DOSE IN RADS
0
20
40
60
80
100
120
140
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL WSEG
UPDATED MODEL


2 MT SURFACE BURST, 100% FISS YIELD
24 HR ACC DOSE VS DWD
DELFIC
ORIGINAL WSEG
UPDATED MODEL
24 HOUR ACCUMULATED DOSE IN RADS
10,000
1000
100
0
20
40
60
80
100
120
140
DOWNWIND DISTANCE IN ST. MILES

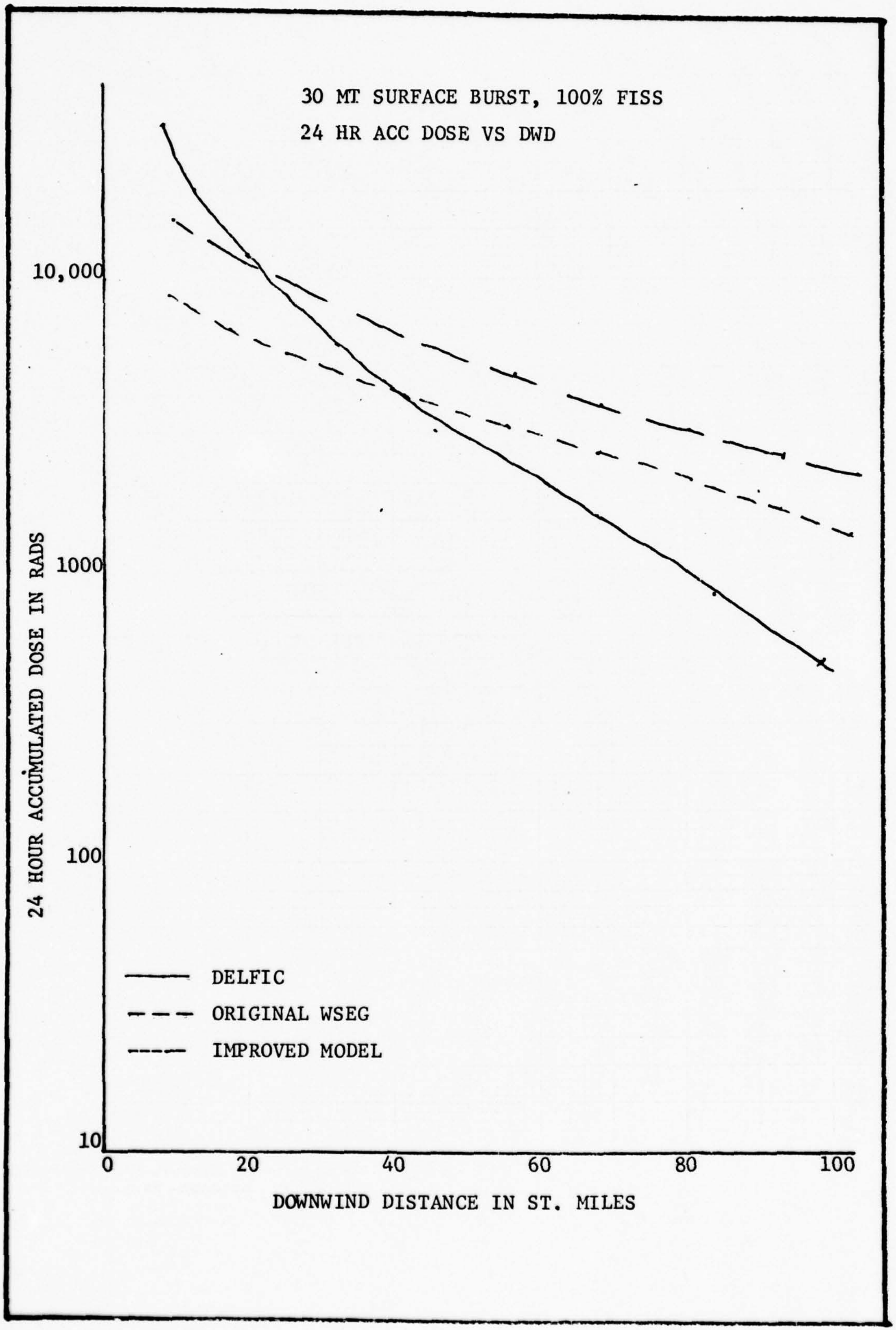


5 MT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
DELFIC
ORIGINAL WSEG
UPDATED MODEL
24 HOUR ACCUMULATED DOSE IN RADS
10,000
1000
100
40
0
30
60
90
120
150
180
210
DOWNWIND DISTANCE IN ST. MILES


10 MT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
DELFIC
ORIGINAL WSEG
UPDATED MODEL
24 HOUR ACCUMULATED DOSE IN RADS
10,000
1000
100
50
0
30
60
90
120
150
180
210
DOWNWIND DISTANCE IN ST. MILES



30 MT SURFACE BURST, 100% FISS
4 HR ACC DOSE VS DWD
10,000
1000
100
10
4 HOUR ACCUMULATED DOSE IN RADS
0
10
20
30
40
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL WSEG
UPDATED MODEL

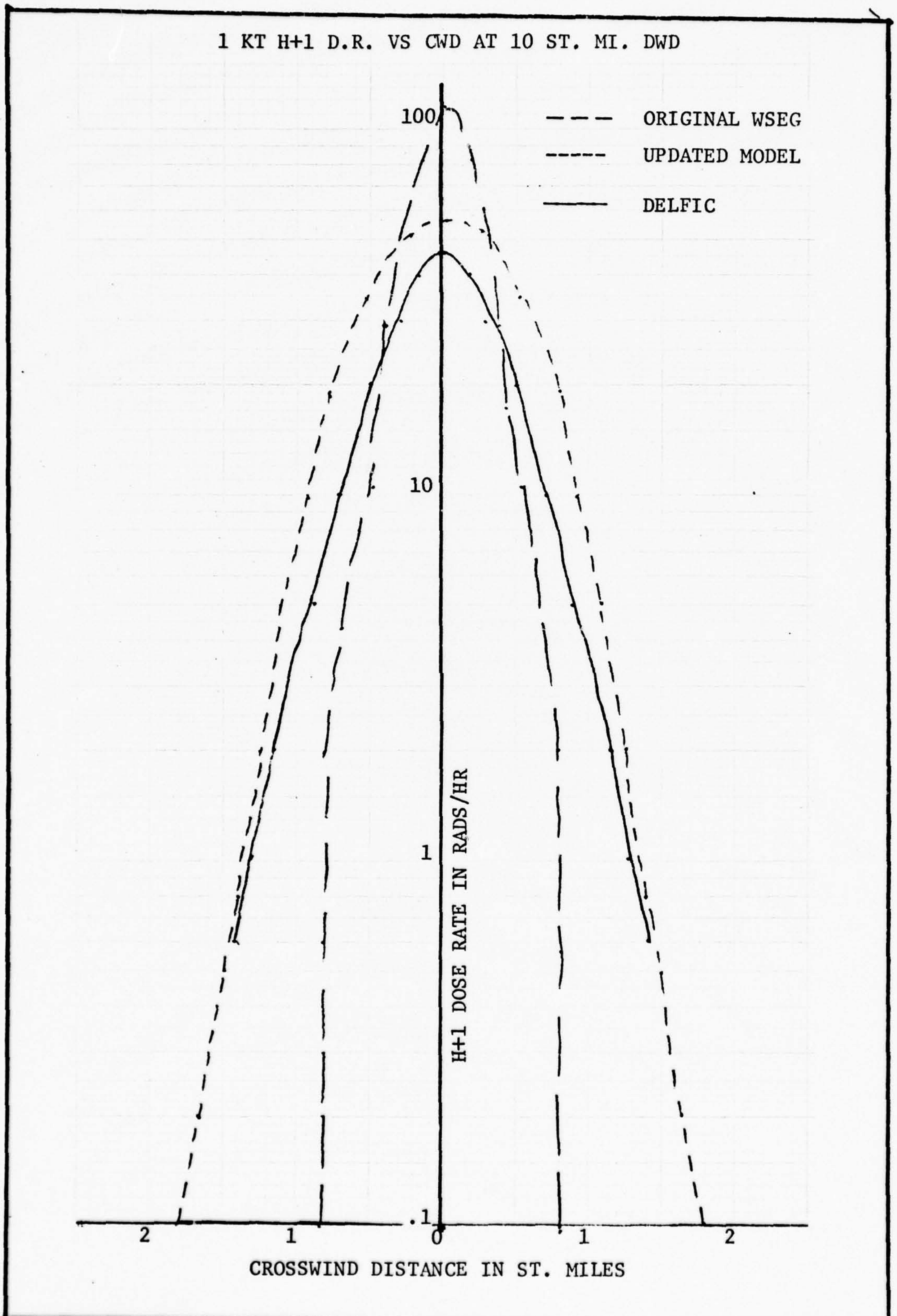


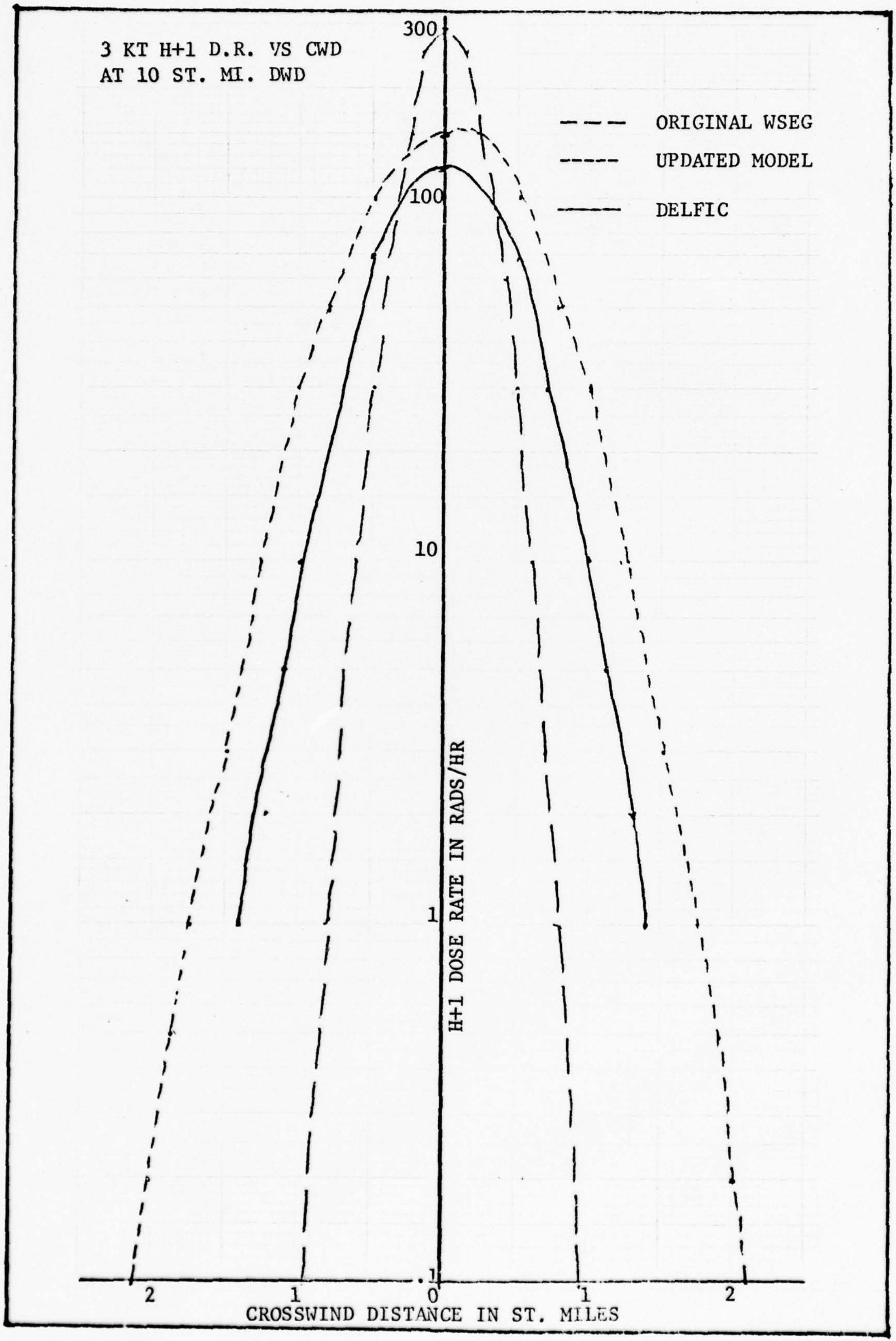
30 MT SURFACE BURST, 100% FISS
24 HR ACC DOSE VS DWD
24 HOUR ACCUMULATED DOSE IN RADS
10,000
1000
100
10
0
20
40
60
80
100
DOWNWIND DISTANCE IN ST. MILES
DELFIC
ORIGINAL WSEG
IMPROVED MODEL

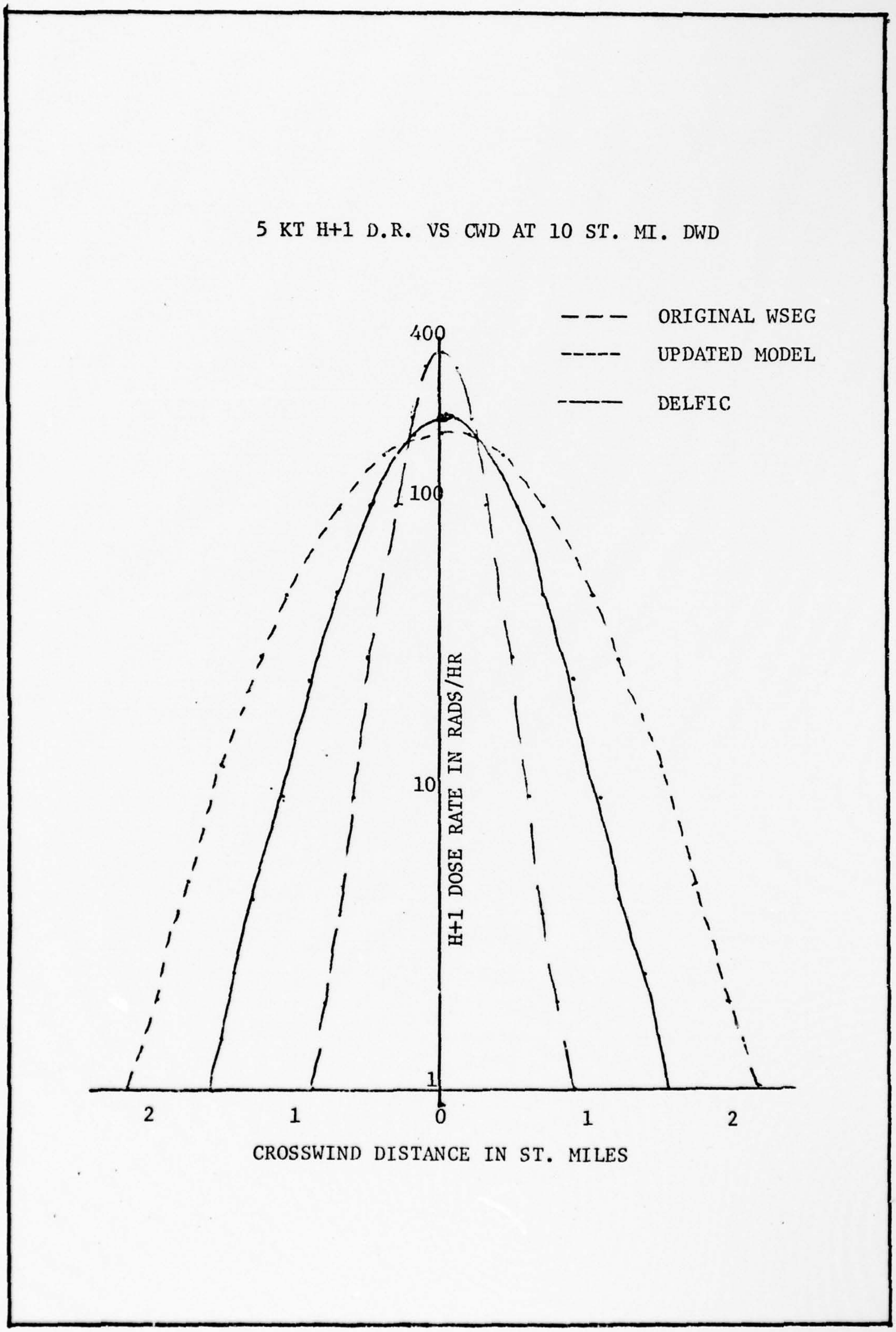
Appendix F

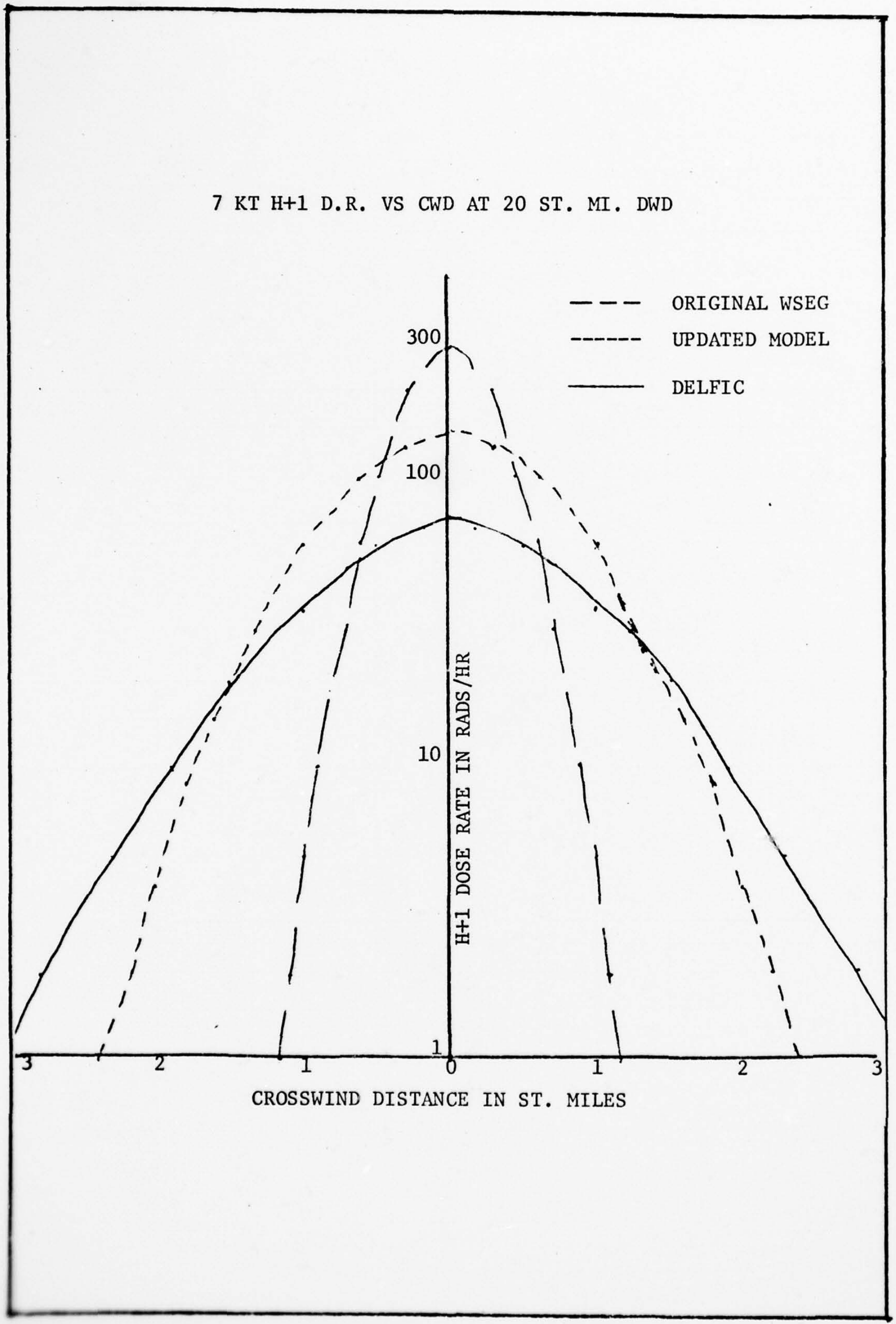
Isodose Contour Width Comparison

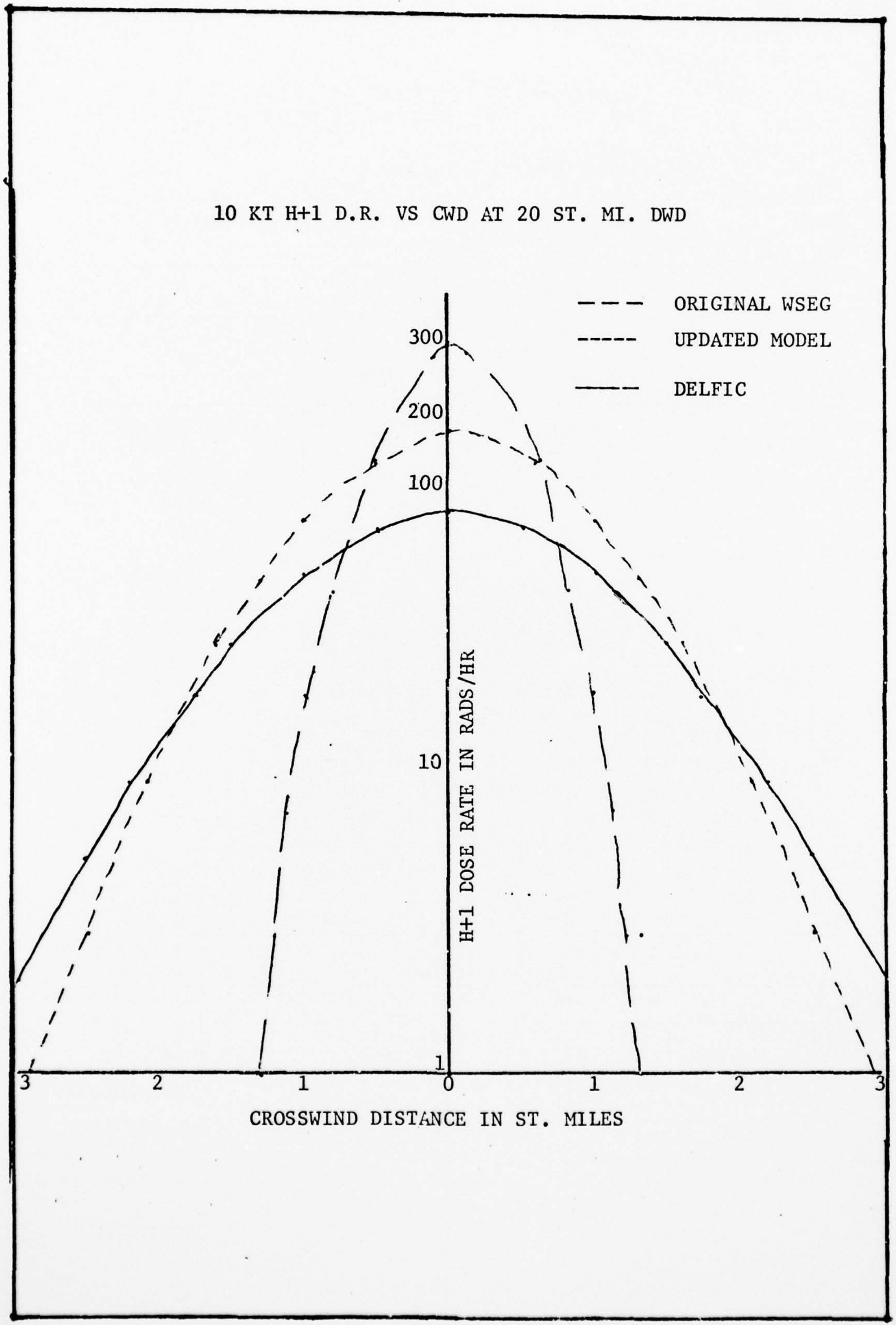
This appendix presents contour width comparisons between the original and improved WSEG models and DELFIC for several yields at selected downwind distances. No ground roughness factor is applied. All data is for 100% fission yield devices detonated at the surface of the earth. The output plotted is the normalized unit reference dose rate ($\dot{D}_{H+1}$).

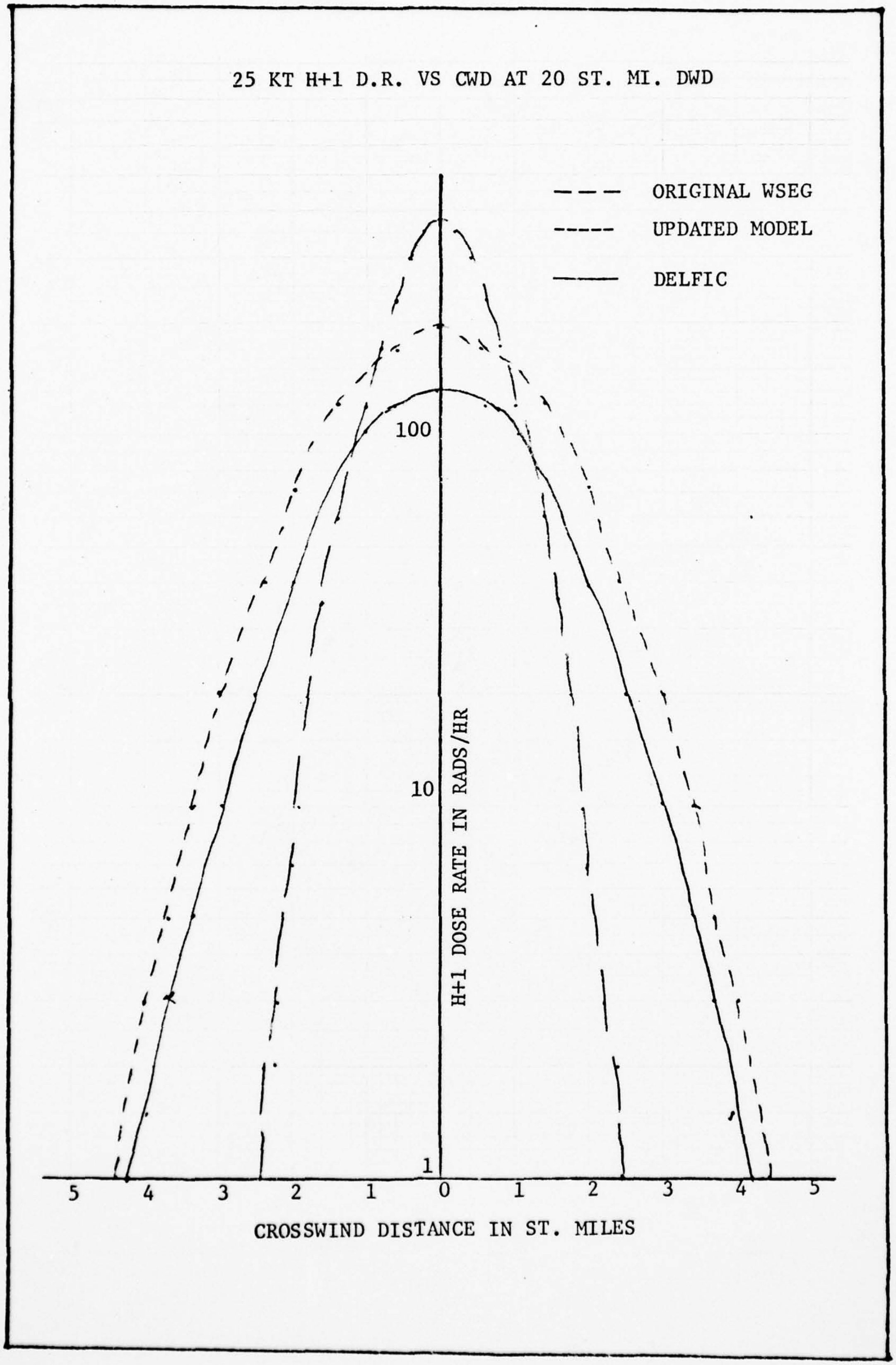

1 KT H+1 D.R. VS CWD AT 10 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
100
10
1
.1
H+1 DOSE RATE IN RADS/HR
2
1
0
1
2
CROSSWIND DISTANCE IN ST. MILES

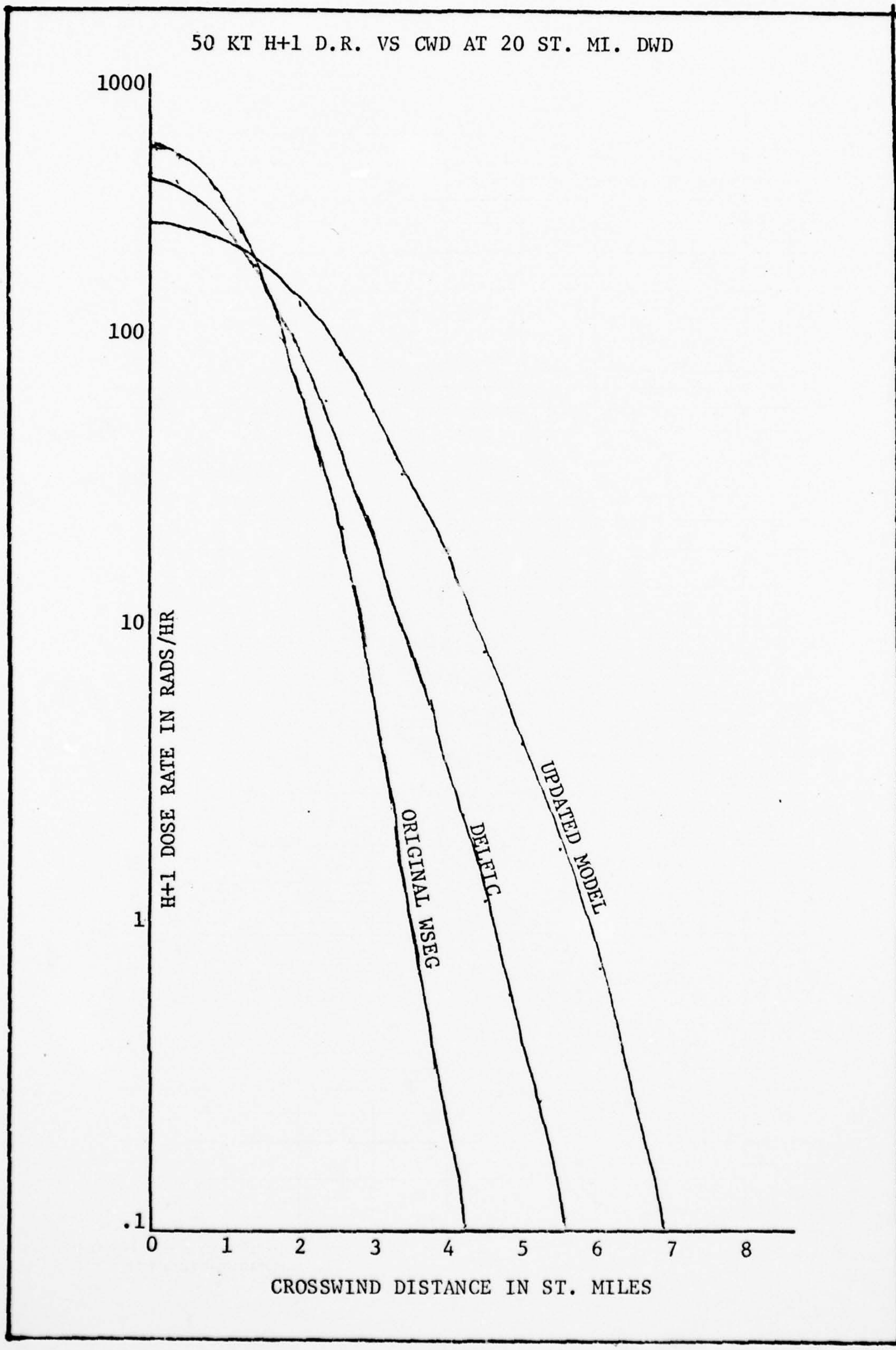

3 KT H+1 D.R. VS CWD
AT 10 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
300
100
10
1
.1
H+1 DOSE RATE IN RADS/HR
2
1
0
1
2
CROSSWIND DISTANCE IN ST. MILES

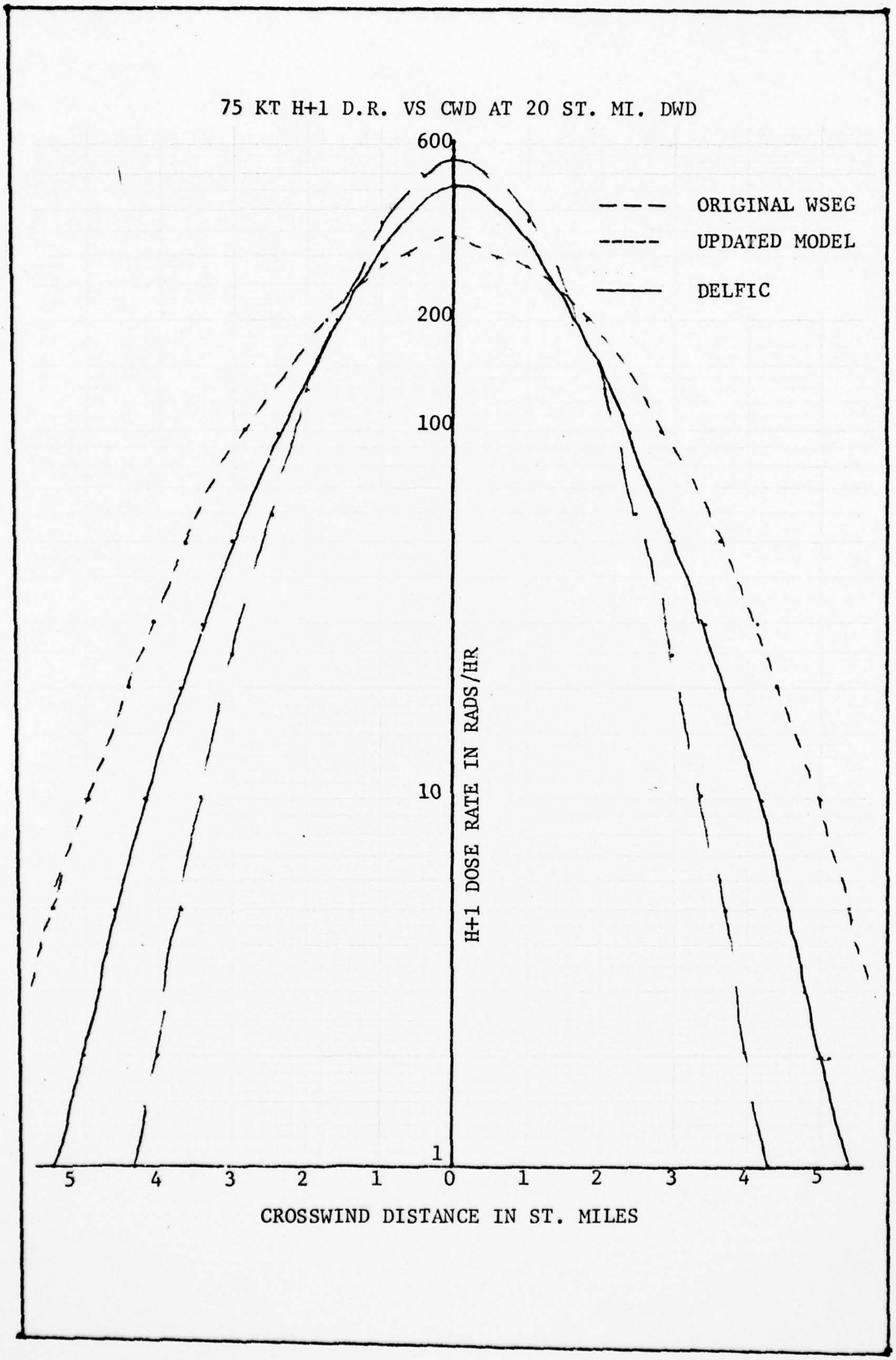

5 KT H+1 D.R. VS CWD AT 10 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
400
100
10
1
H+1 DOSE RATE IN RADS/HR
2
1
0
1
2
CROSSWIND DISTANCE IN ST. MILES


7 KT H+1 D.R. VS CWD AT 20 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
300
100
10
1
H+1 DOSE RATE IN RADS/HR
3
2
1
0
1
2
3
CROSSWIND DISTANCE IN ST. MILES

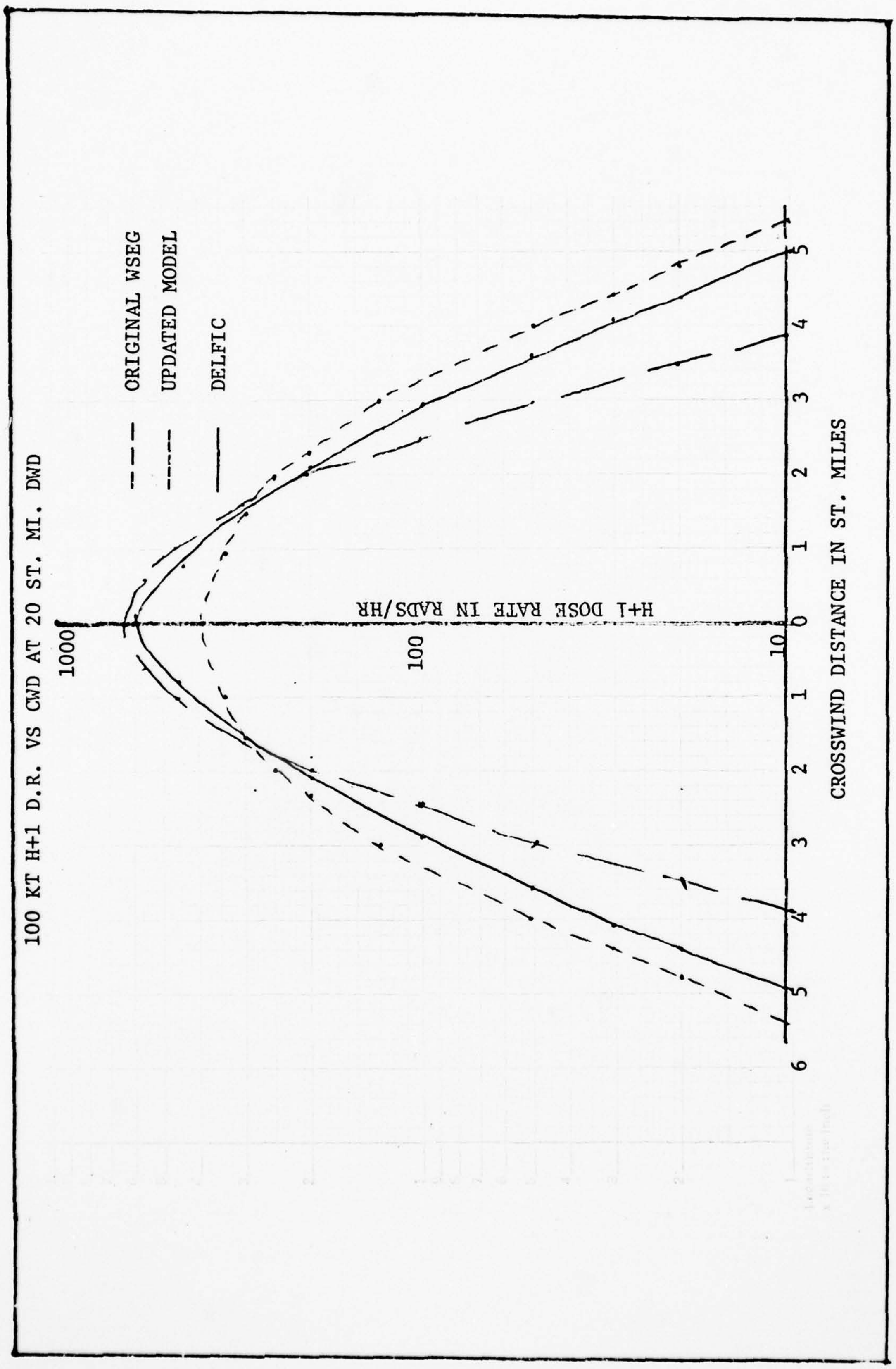

10 KT H+1 D.R. VS CWD AT 20 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
300
200
100
10
1
H+1 DOSE RATE IN RADS/HR
3
2
1
0
1
2
3
CROSSWIND DISTANCE IN ST. MILES


25 KT H+1 D.R. VS CWD AT 20 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
100
10
1
H+1 DOSE RATE IN RADS/HR
5 4 3 2 1 0 1 2 3 4 5
CROSSWIND DISTANCE IN ST. MILES

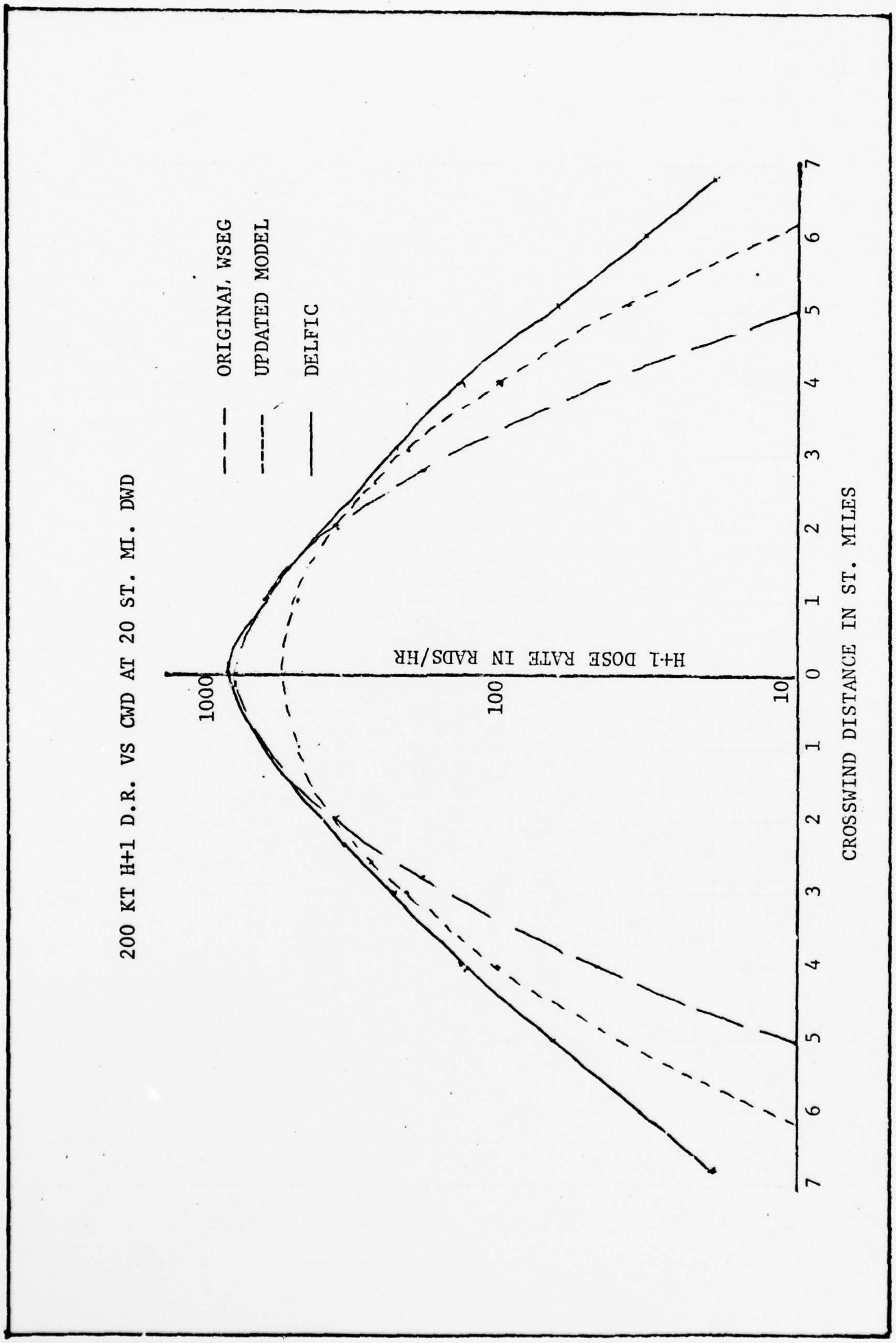

50 KT H+1 D.R. VS CWD AT 20 ST. MI. DWD
1000
100
10
1
.1
0
1
2
3
4
5
6
7
8
H+1 DOSE RATE IN RADS/HR
CROSSWIND DISTANCE IN ST. MILES
ORIGINAL WSEG
DELFIC
UPDATED MODEL

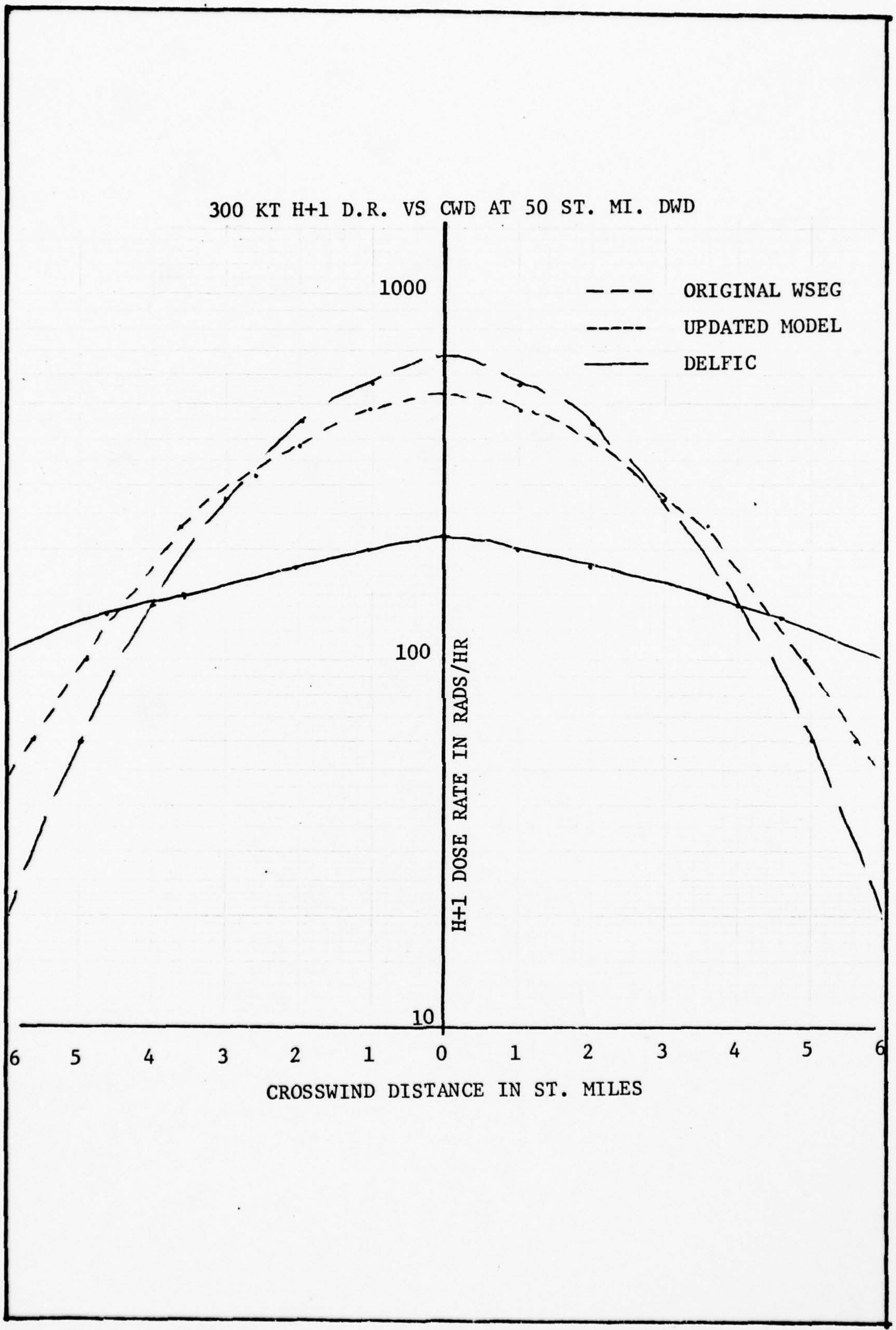


75 KT H+1 D.R. VS CWD AT 20 ST. MI. DWD
600
200
100
10
1
ORIGINAL WSEG
UPDATED MODEL
DELFIC
H+1 DOSE RATE IN RADS/HR
5 4 3 2 1 0 1 2 3 4 5
CROSSWIND DISTANCE IN ST. MILES

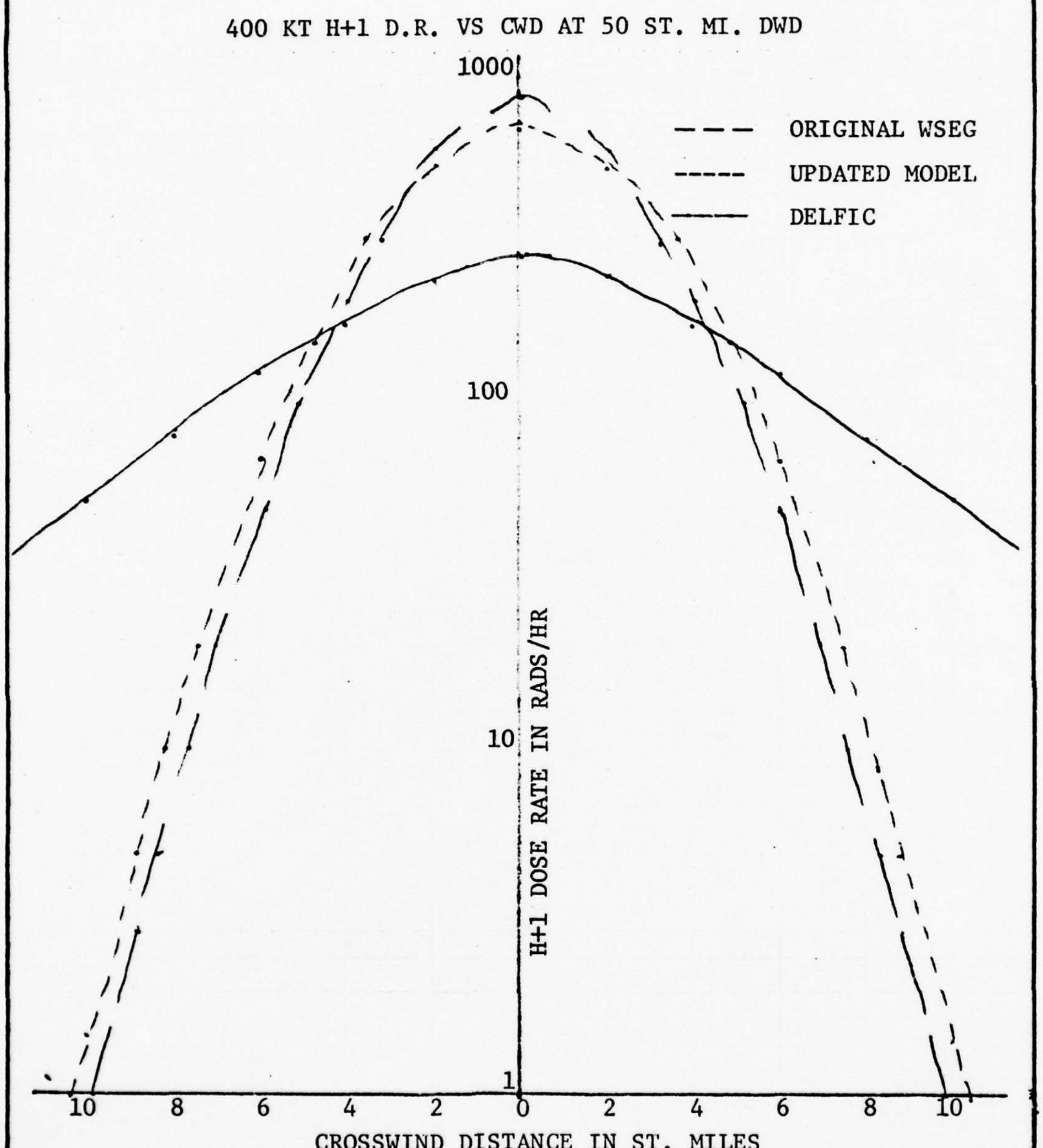


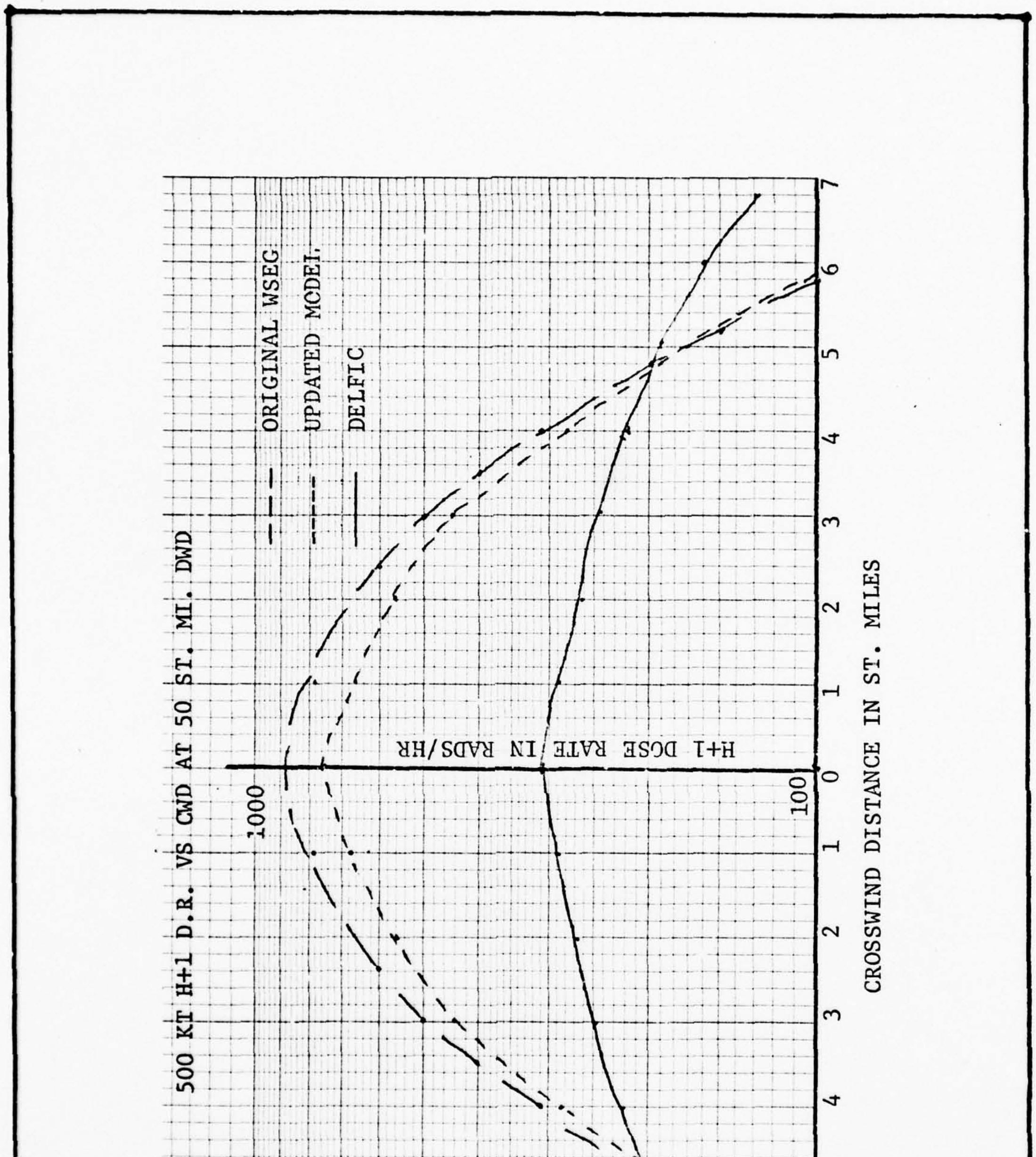
100 KT H+1 D.R. VS CWD AT 20 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
H+1 DOSE RATE IN RADS/HR
1000
100
10
CROSSWIND DISTANCE IN ST. MILES
6
5
4
3
2
1
0
1
2
3
4
5


200 KT H+1 D.R. VS CWD AT 20 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
H+1 DOSE RATE IN RADS/HR
1000
100
10
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
CROSSWIND DISTANCE IN ST. MILES

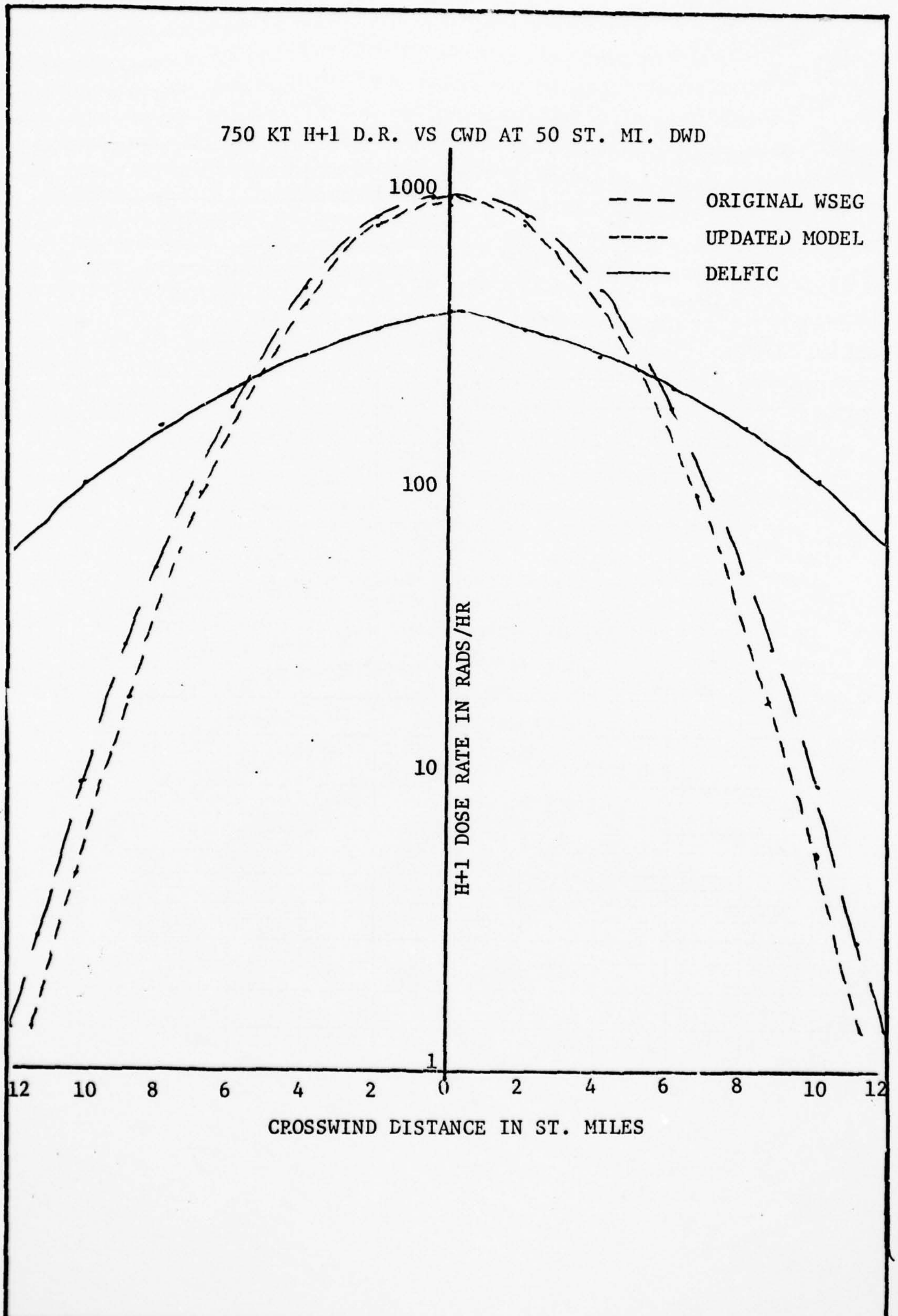


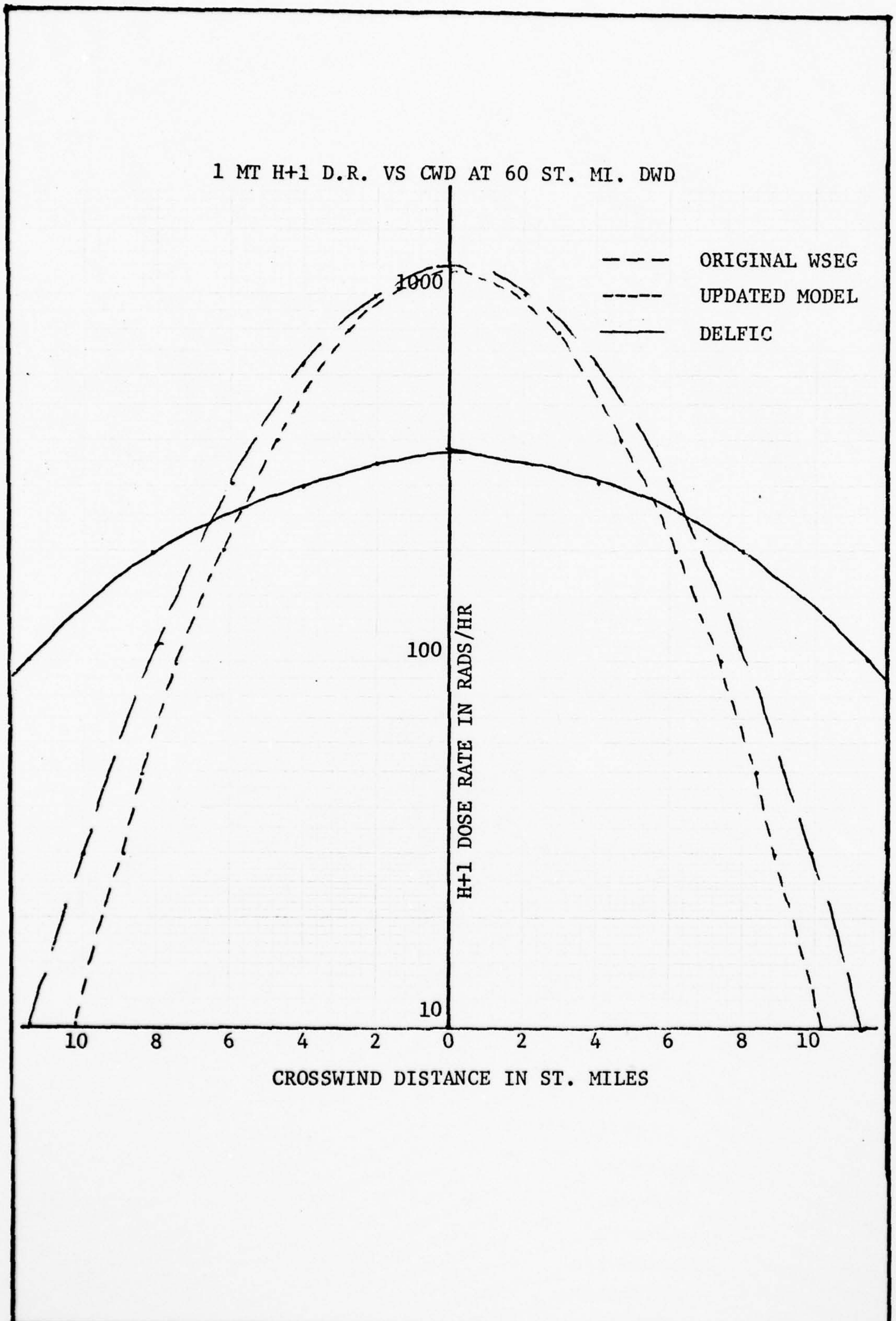
300 KT H+1 D.R. VS CWD AT 50 ST. MI. DWD
1000
100
10
ORIGINAL WSEG
UPDATED MODEL
DELFIC
H+1 DOSE RATE IN RADS/HR
6 5 4 3 2 1 0 1 2 3 4 5 6
CROSSWIND DISTANCE IN ST. MILES


400 KT H+1 D.R. VS CWD AT 50 ST. MI. DWD
1000
100
10
1
ORIGINAL WSEG
UPDATED MODEL
DELFIC
H+1 DOSE RATE IN RADS/HR
10 8 6 4 2 0 2 4 6 8 10
CROSSWIND DISTANCE IN ST. MILES

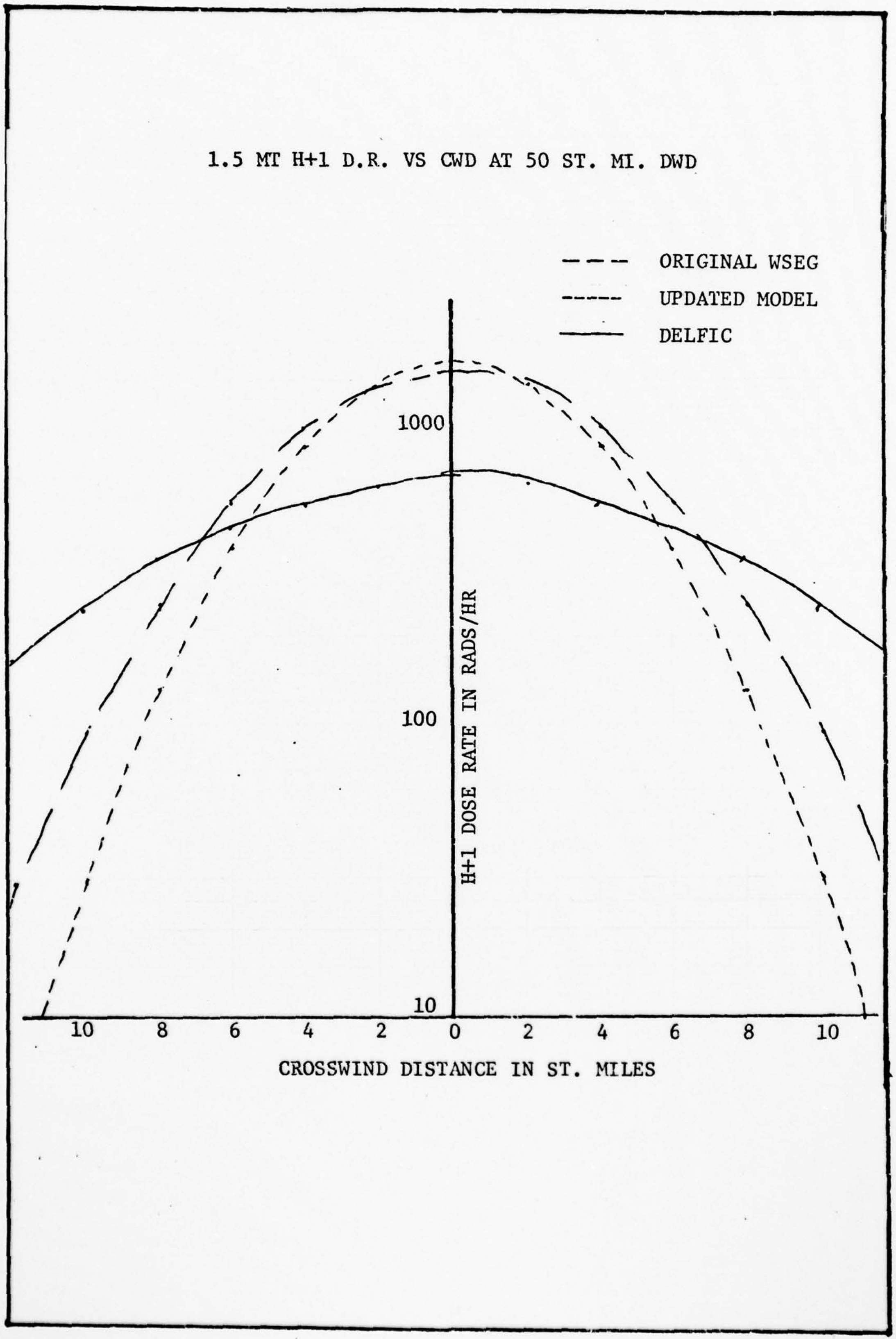


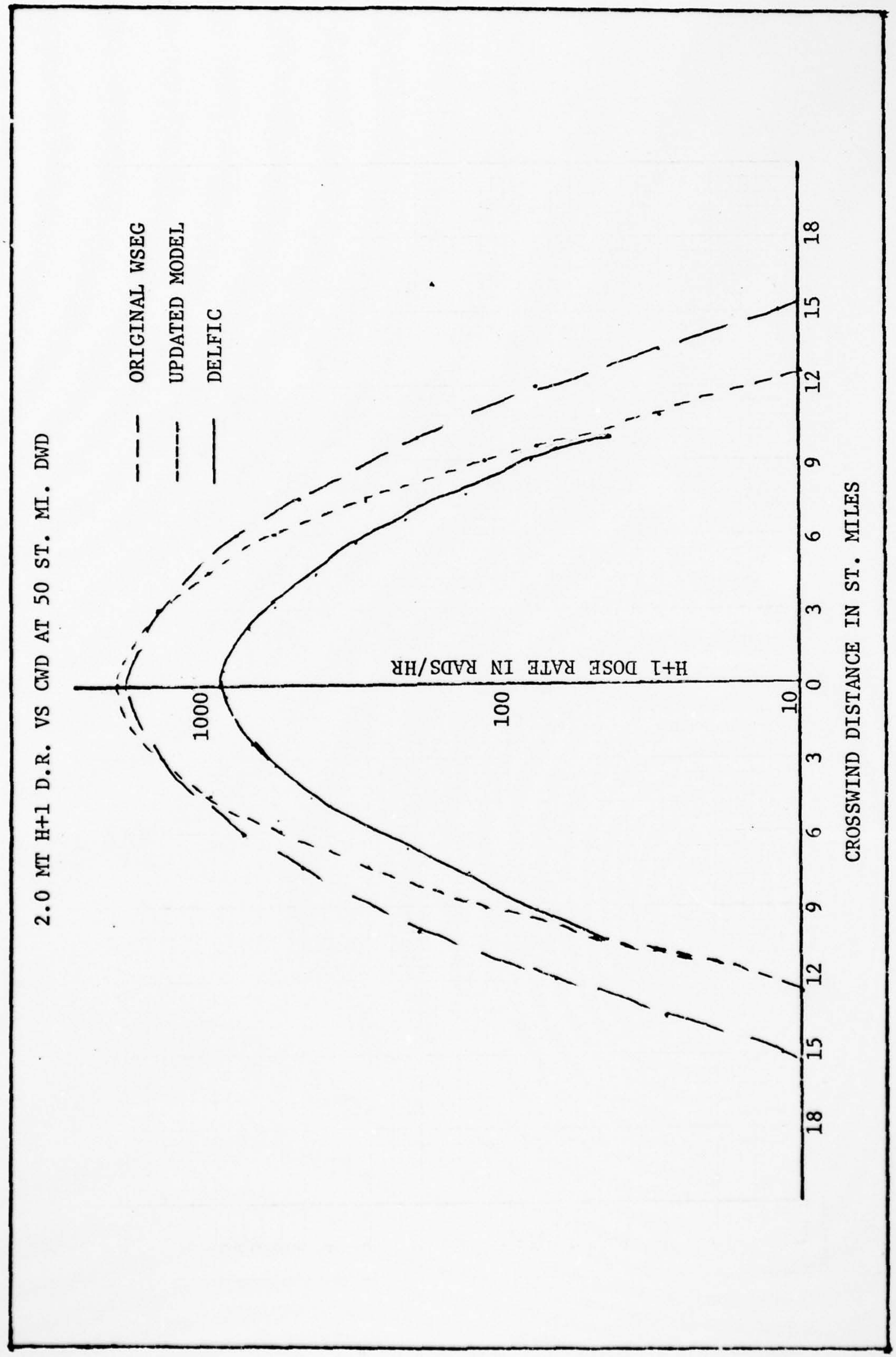
500 KT H+1 D.R. VS CWD AT 50 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
H+1 DOSE RATE IN RADS/HR
1000
100
CROSSWIND DISTANCE IN ST. MILES
7 6 5 4 3 2 1 0 1 2 3 4 5 6 7
1 9 8 7 6 5 4 3 2 1


750 KT H+1 D.R. VS CWD AT 50 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
1000
100
10
1
H+1 DOSE RATE IN RADS/HR
12 10 8 6 4 2 0 2 4 6 8 10 12
CROSSWIND DISTANCE IN ST. MILES



1 MT H+1 D.R. VS CWD AT 60 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
1000
100
10
H+1 DOSE RATE IN RADS/HR
10
8
6
4
2
0
2
4
6
8
10
CROSSWIND DISTANCE IN ST. MILES


1.5 MT H+1 D.R. VS CWD AT 50 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
1000
100
10
H+1 DOSE RATE IN RADS/HR
10
8
6
4
2
0
2
4
6
8
10
CROSSWIND DISTANCE IN ST. MILES



2.0 MT H+1 D.R. VS CWD AT 50 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
H+1 DOSE RATE IN RADS/HR
1000
100
10
18
15
12
9
6
3
0
3
6
9
12
15
18
CROSSWIND DISTANCE IN ST. MILES

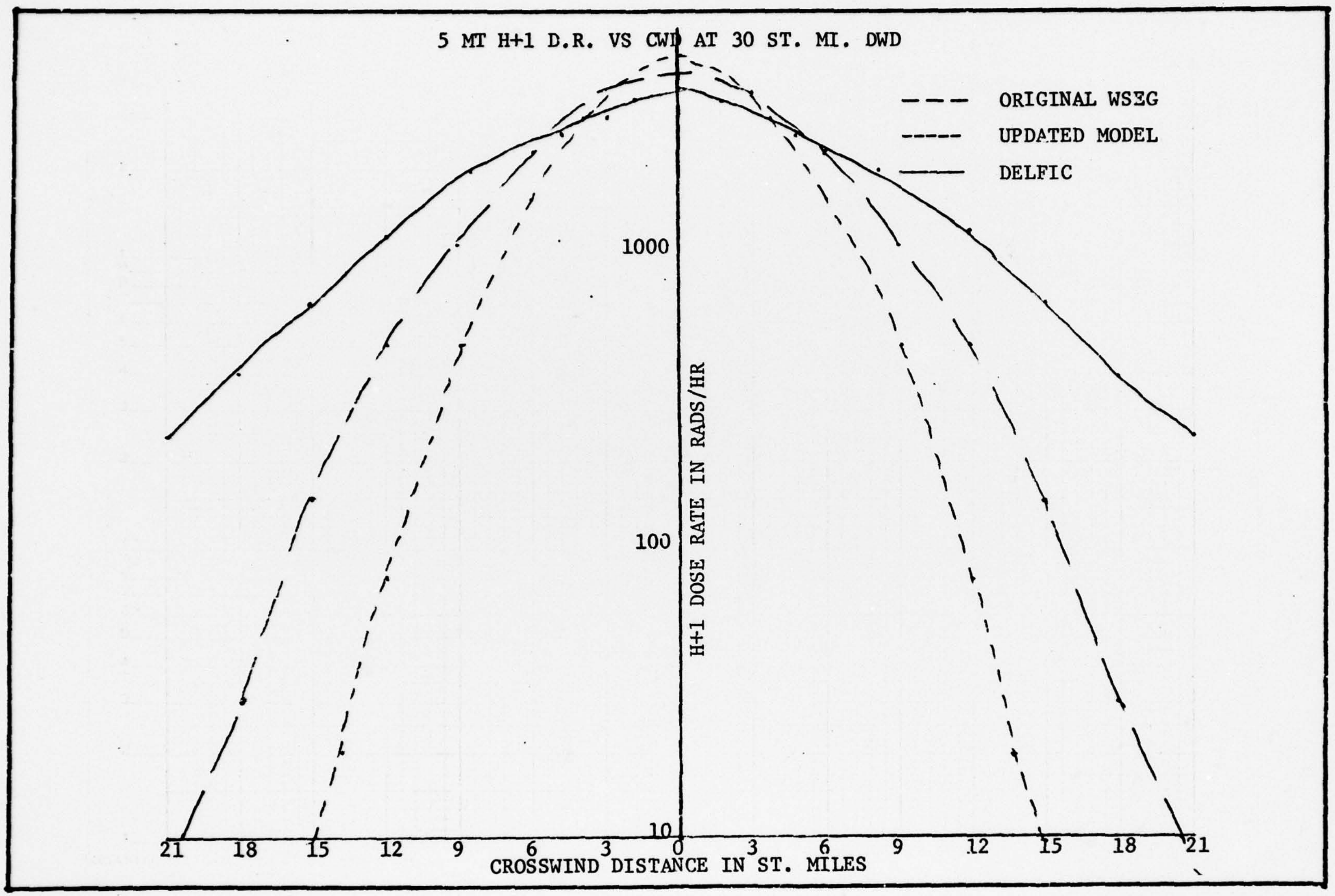
AD-A063 957 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCH--ETC F/G 18/3
AN IMPROVEMENT TO THE WSEG FALLOUT MODEL LOW YIELD PREDICTION C--ETC(U)
DEC 78 N H RUOTANEN

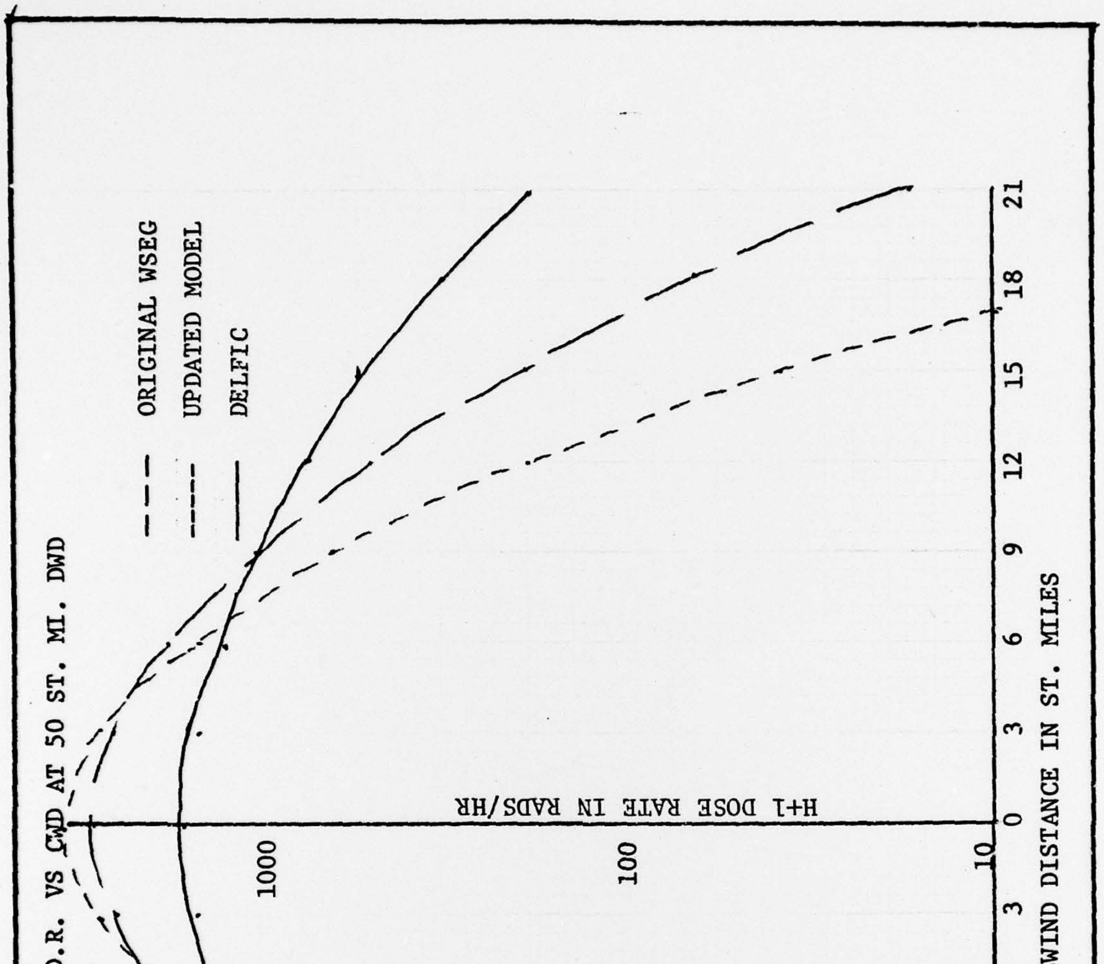
UNCLASSIFIED AFIT/GNE/PH/78D-23 NL

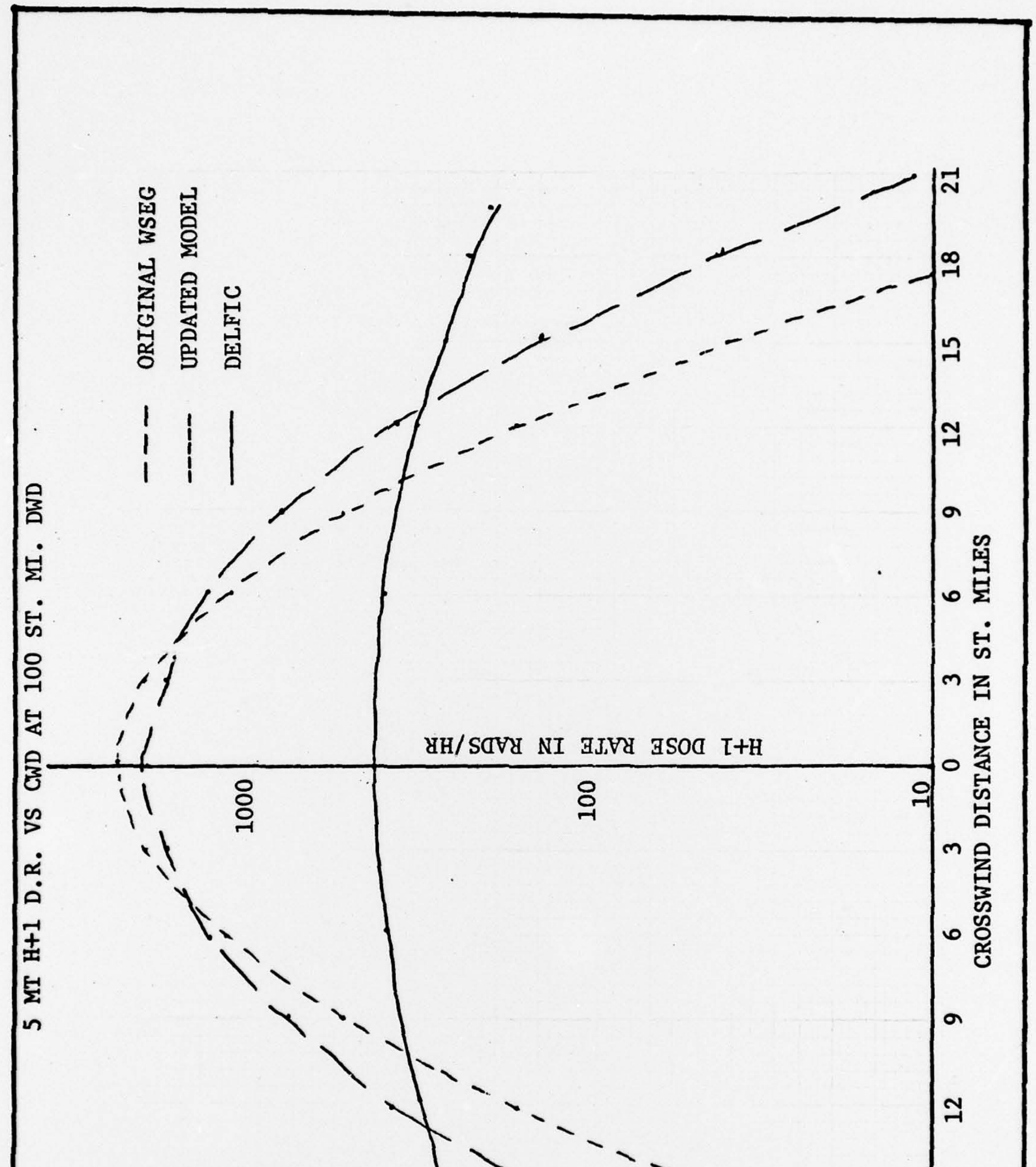
2 OF 2

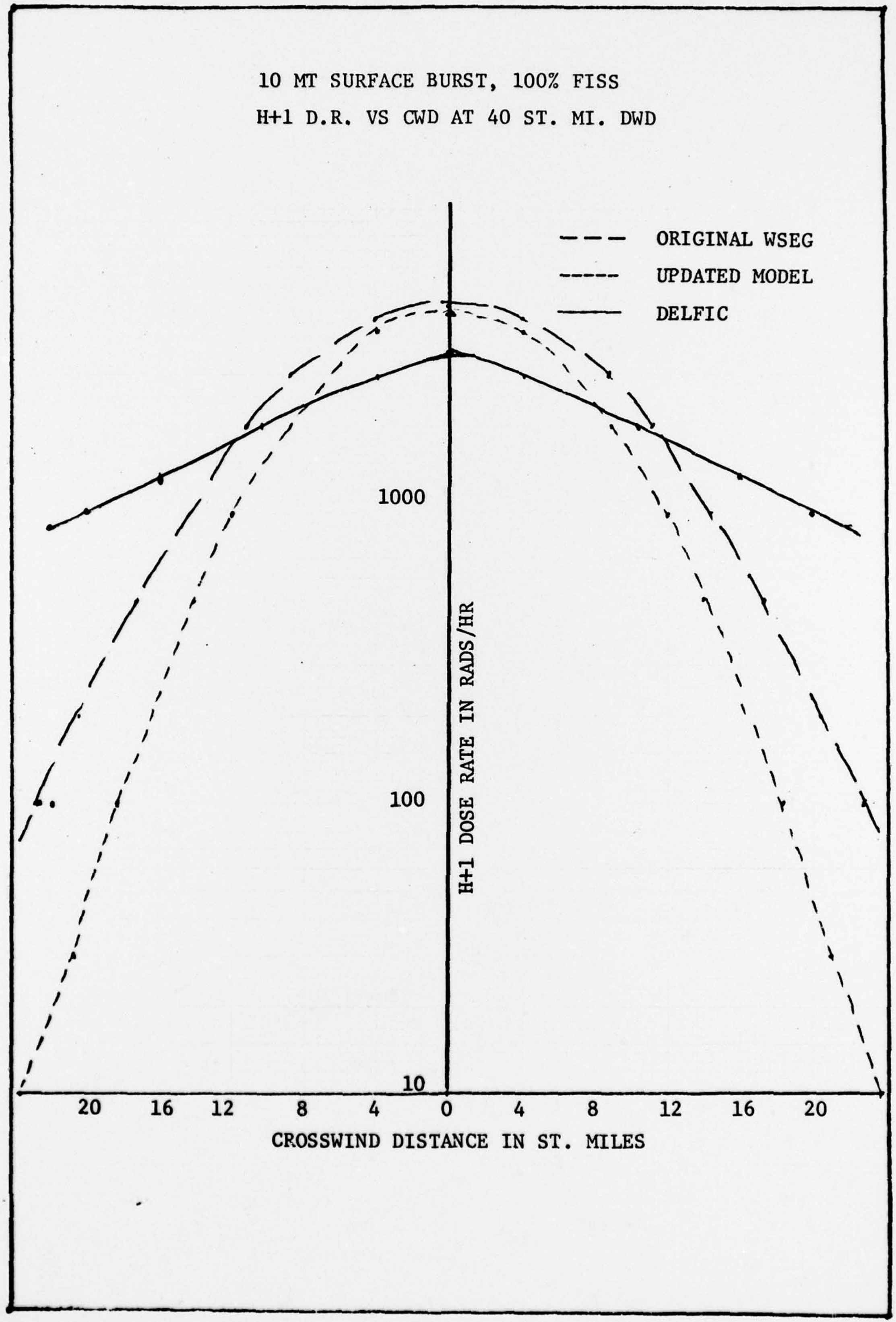
AD A063957

END
DATE
FILMED
4-79
DDC

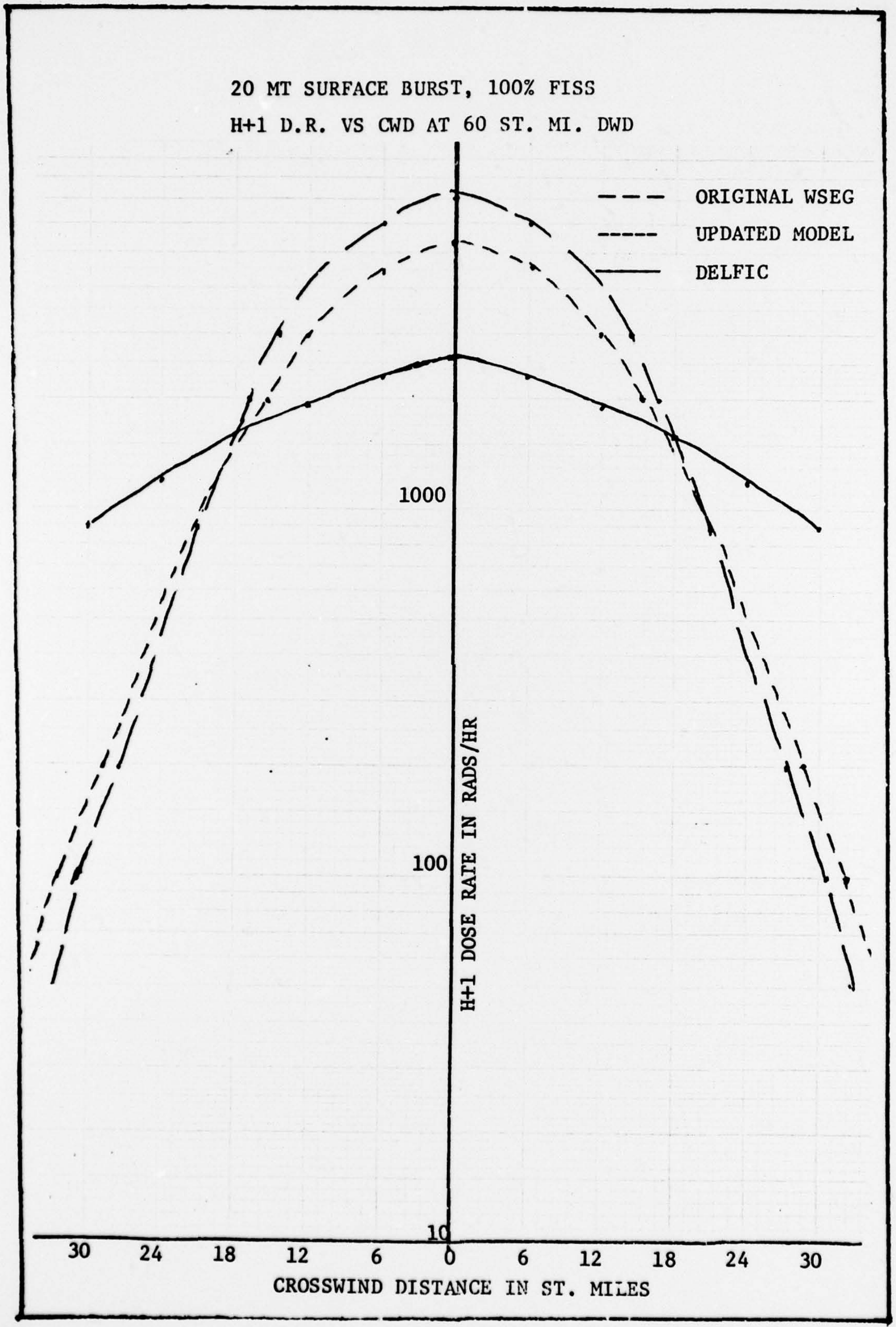

5 MT H+1 D.R. VS CWD AT 30 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
H+1 DOSE RATE IN RADS/HR
1000
100
10
21 18 15 12 9 6 3 0 3 6 9 12 15 18 21
CROSSWIND DISTANCE IN ST. MILES

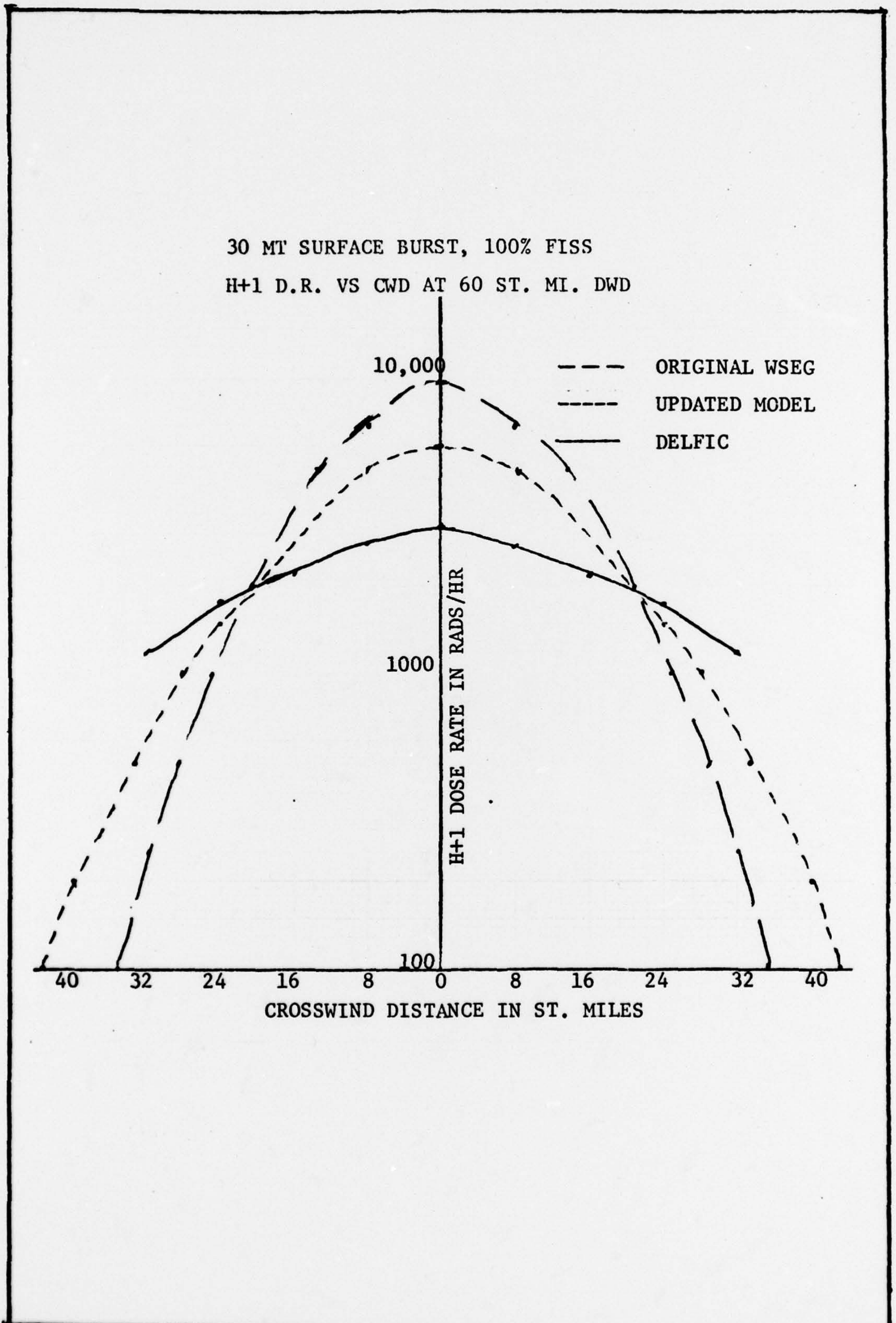

5 MT H+1 D.R. VS CWD AT 50 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
H+1 DOSE RATE IN RADS/HR
1000
100
10
21 18 15 12 9 6 3 0 3 6 9 12 15 18 21
CROSSWIND DISTANCE IN ST. MILES


5 MT H+1 D.R. VS CWD AT 100 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
H+1 DOSE RATE IN RADS/HR
1000
100
10
21 18 15 12 9 6 3 0 3 6 9 12 15 18 21
CROSSWIND DISTANCE IN ST. MILES



10 MT SURFACE BURST, 100% FISS
H+1 D.R. VS CWD AT 40 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
1000
100
10
H+1 DOSE RATE IN RADS/HR
20
16
12
8
4
0
4
8
12
16
20
CROSSWIND DISTANCE IN ST. MILES


20 MT SURFACE BURST, 100% FISS
H+1 D.R. VS CWD AT 60 ST. MI. DWD
ORIGINAL WSEG
UPDATED MODEL
DELFIC
1000
100
10
H+1 DOSE RATE IN RADS/HR
30
24
18
12
6
0
6
12
18
24
30
CROSSWIND DISTANCE IN ST. MILES


30 MT SURFACE BURST, 100% FISS
H+1 D.R. VS CWD AT 60 ST. MI. DWD
10,000
1000
100
ORIGINAL WSEG
UPDATED MODEL
DELFIC
H+1 DOSE RATE IN RADS/HR
40
32
24
16
8
0
8
16
24
32
40
CROSSWIND DISTANCE IN ST. MILES

VITA

Norman Henry Ruotanen was born on 27 June 1947 in Hancock, Michigan, the son of Henry A. Ruotanen and Winifred Kangas Ruotanen. He graduated from high school in Ontonagon, Michigan in 1965. In June 1969, he graduated from Illinois Institute of Technology with a Bachelor of Science degree and was then commissioned a second lieutenant in the United States Air Force through the ROTC program. He attended pilot training at Laredo, Texas and received his wings there in July 1970. Two years of flying the C-141 transport for Military Airlift Command followed. During the next five years, he served as aircrew commander, instructor pilot, and pilot flight examiner on B-52-H and B-52-D bomber aircraft. He graduated from Northern Michigan University in May 1977 with the degree of Master of Arts in Public Administration. In June 1977, he entered the Graduate Nuclear Engineering program at the School of Engineering, Air Force Institute of Technology.

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This Thesis typed by Ms. Cheryl Gilliland